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A REPORT ON THE PUBLIC HEALTH ASPECTS OF CLAMMING IN RARITAN BAY

Robert W. Kehr, et al

Public Health Service
Washington, D.C.

1941

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I. INTRODUCTION.

The survey of Raritan Bay* waters herein reported had its inception in the request, from the New York State Conservation Department, for a ruling by the U.S. Public Health Service, on the suitability of the waters of the Great Kills-Princess Bay area in Raritan Bay for the taking of market clams. This area was closed in 1925, but was reopened in 1940 with the requirement that sewage from the Oakwood Beach and Cromwell Avenue screening plants on Staten Island be continuously chlorinated. Studies made by the New York State Conservation Department during the summer of 1940 indicated that waters of the area were of doubtful sanitary quality for the taking of clams. Therefore, it was deemed desirable to make a rather detailed survey and to attempt to formulate a definite standard defining the allowable limits of pollution within which the public health would not be endangered by the taking of clams from the area.

The survey covered practically the entire period of April, May and June, 1941, and was made by three cooperating laboratories whose procedures were coordinated under the immediate direction and supervision of the U. S. Public Health Service.

It was obviously impossible, with the limited time and funds available, to attempt basic research on the general problems

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(*) The term, Raritan Bay, as used in this report includes Raritan Bay proper, Sandy Hook Bay and Lower Bay.

of public health involved in the production and marketing of shellfish and the conclusions drawn are, therefore, largely limited in their application to the taking of hard clams from Raritan Bay. The general procedure used in attacking the problem may, however, find partial application in the solution of similar problems elsewhere.

The routine work of the survey was conducted almost entirely by the organizations listed on the title page and their wholehearted cooperation was manifest throughout the survey. In addition, numerous others have generously assisted in the study, namely, Mr. Sol Pincus, Dr. Samuel Frant and Mr. R. Miller, of the New York City Department of Health; Professor Earle B. Phelps of Columbia University; Mr. Seth G. Hess of the Interstate Sanitation Commission; and Mr. R. H. Gould and Mr. Wellington Donaldson of the New York City Department of Public Works. The Sanitary Engineering Division of the New Jersey State Department of Health, Mr. H. P. Croft, Chief Engineer, furnished data on sewage treatment and drainage areas in New Jersey. The survey is also greatly indebted to the U. S. Geological Survey, District Offices for New Jersey and New York, under O. M. Hartwell and A. W. Harrington, respectively, for the hydrometric data on fresh water discharges.

Federal Security Agency

United States Public Health Service

1941

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Based on Studies Made Under Supervision of the
U. S. Public Health Service

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II. THE RARITAN BAY STUDY.

General Considerations

The pollution of waters in the vicinity of New York City has been the subject of frequent studies and reports since about the beginning of this century. These reports, and particularly the excellent theoretical analyses of conditions by Professor Earle B. Phelps, have been drawn upon heavily in this present study inasmuch as it has not been possible to go beyond the waters of Raritan Bay and its various inlets in the measurement of pollution. Some consideration, however, must be given pollution beyond these limits because the complicated movements of waters greatly affect conditions in Raritan Bay by transportation of pollution and by the furthering of its encroachment through mechanical displacement and mixing.

A general picture of the waterways in the New York area can be seen in Figure 1. Pollution of the eastern part of

(Insert Figure 1)

Raritan Bay is dominated by that discharged through the Narrows and possibly to a very limited extent by that coming from Jamaica Bay through Rockaway Inlet. This water surges back and forth through the Narrows and is acted upon, in addition to the forces of natural purification, according to Phelps and Velz(1) largely by three factors, "the land water runoff, which exerts the same effect as in any fresh water river; the oscillatory movements of the tides; and the up-flow of sea water." Conditions are further complicated by a slight net movement of water with each tidal cycle through Kill van Kull, the East River and the Harlem River into the Hudson River - Upper Bay system and out through the Narrows. Movement through Kill van Kull complicates the picture somewhat for the Newark Bay - Arthur Kill system which receives drainage from the Hackensack and Passaic Rivers. Both Arthur Kill and Raritan River discharge into a common pool at the upper end of Raritan Bay and the picture of this end of Raritan Bay is controlled by the pollution received from these two sources.

In view of the limited time and facilities available for the study of Raritan Bay and of clamming operations within the bay, the field work of this survey was largely limited to the following studies:

I. The collection of data on the sources of pollution of areas adjacent to the bay, fresh water discharge measurements (from the U. S. Geological Survey), meteorological and other miscellaneous data needed for the study.

II. Measurement of pollution throughout several tidal cycles at the four main inlets to the Lower Bay area: Raritan River, Arthur Kill, the Narrows and Rockaway Inlet. This work was done by the Water, Sewage and Shellfish Laboratory of the New York City Health Department.

III. Measurement of pollution present throughout Raritan Bay during the months of May and June, 1941. The collection and analyses of these samples was done by the New York State Conservation Department Laboratory at Freeport, and by the New

Jersey State Department of Health Shellfish Laboratory at Highlands, N. J.

IV. The examination of disintegrated clam meats from various areas of Raritan Bay.

This work was carried on by both state laboratories along with the measurement of the bacterial content of bay waters under III.

V. Studies in the isolation of enteric pathogens. This work was done by the Typhoid Fever Laboratory of the New York City Department of Health, largely upon pooled samples collected for the measurement of coliforms and total counts at the various inlets to Raritan Bay under II.

Laboratory Methods

Bacteriological examinations were made of bay water and shell hard clam samples. These were collected at definite points of the Raritan Bay area under conditions of depth and tide described elsewhere in this report. The examinations made consisted of:

(1) Determination of the total number of bacteria which developed on tryptone-glucose extract agar in 48 hours at 37°C.

(2) Determination of the coliform group, as shown by the results of fermentation tests. Standard lactose broth was used for the presumptive test, and brilliant green bile lactose broth for confirmation.

In the coliform determination, for the presumptive test, series of standard lactose broth fermentation tubes were inoculated with appropriate quantities of samples under test, these being such that usually all the tubes in the lowest dilution were positive for gas formation, and all the tubes in the highest dilution negative, with the results in the intermediate dilutions variable, when a series of tubes were planted in three decimal dilutions. Quintuplicate tubes were inoculated in each dilution. The results were interpreted by M.P.N. values secured from Hoskins Tables, found in Public Health Reports Reprint No. 1621.

At the inception of this study, it was felt that any method of bacteriological examination of shellfish should include the whole of the meats and liquor of the shellfish, inasmuch as this most nearly approximates the portions consumed when eating raw shellfish. Furthermore, the total picture of bacteria present was desirable in order to allow more accurate quantitative work. These conditions could be met with a minimum of technical difficulty by complete disintegration or emulsification of the mixed clam meats and shell liquor. Several types of mixers* using rotating knife blades (12 - 15,000 r.p.m.) which do satisfactory work are available commercially and present few problems in routine use.

To insure uniformity of procedure in the preparation of shellfish meats for examination in the various laboratories concerned, a uniform method of disintegrating such samples was adopted.

(*) The two types mentioned on page 139, Standard Methods for the Examination of Dairy Products, Eighth Edition (1941), were found satisfactory.

This consisted in the emulsification of the sample (meats, liquor, etc.) in an electric disintegrator. The disintegrator employed, which was identical for all laboratories, produced a very thorough and complete emulsification of the shellfish samples. Comparative results, which were carried out, indicated that this step was a very important one in the standardization of procedures, leading to more uniform results.

To standardize the essential materials in the laboratories collaborating in this survey, it was agreed that all bacteriological culture media employed, namely, standard lactose broth, brilliant green bile lactose broth (2%) and tryptone glucose extract agar, be secured in dehydrated form of the same lot number, from the Digestive Ferments Company, and prepared for use according to their instructions. Care was also taken to insure the use of standard equipment in all the participating laboratories.

The term "shellfish" in this report refers to samples of shell hard clams only. The term "coliform group" in this report is considered as including all aerobic and facultative anaerobic Gram negative, non-spore forming bacteria, which ferment lactose with gas formation, and which upon transfer from a gas positive presumptive lactose broth tube to lactose broth containing brilliant green (0.00133%) and bile (2%), produce gas in any amount during 48 hours incubation at 37°C.

Members of the technical personnel of the laboratories participating in this collaborative sanitary survey were given mimeographed copies of "Memorandum of Procedures to be Employed in the Bacteriological Examination of Shellfish and Shellfish Waters". As stated in that memorandum, the methods detailed therewith were based on the following:

(1) "Standard Methods for the Examination of Shellfish", adopted by the Laboratory Section of the American Public Health Association in September, 1920, and published in the 1922 volume of the American Journal of Public Health, page 574.

(2) The revised "Tentative Standard Procedure for the Bacteriological Examination of Shellfish and Shellfish Waters", prepared by the Laboratory Section Committee of the American Public Health Association, under date of December 27, 1940. (Personal communication).

At the inception of the laboratory work, the bacteriologist representing the U. S. Public Health Service, spent an appropriate period of time in each of the collaborating laboratories, actively participating in the establishment of the standard examination procedures proscribed in the previously mentioned memorandum. In addition, the consulting bacteriologist spent twelve days at the beginning of the study assisting in the organization of the work and five days on each of two occasions thereafter advising concerning its progress. It is believed that the continuity in the use of the proscribed standard procedures, the reliability of the results and the method of their recording, was assured by the adequate quality of the technical personnel of the participating laboratories and the local supervision exercised over them.

Nevertheless, a further attempt to guarantee the general adherence to the prescribed procedures and the reliable quality of the results secured and reported, was made in the following four ways:

(1) At definite, almost periodic intervals, the Public Health Service bacteriologist spent between a week and ten days at each of the collaborating laboratories. During such time, this bacteriologist directly observed and actively participated in the carrying out of such steps in the laboratory work as the collecting of sea water and shellfish samples, the preparing of such samples for the analyses proper, and in each of the steps of which the actual examination of the different samples consisted, as well as the calculation and the checking of the final results.

(2) All of these procedures, in particular the sites of collection of samples, the method of collection of samples as well as the calculation of the final results, were carefully checked by the Public Health Service sanitary engineer, who was on duty throughout the investigation.

(3) During his sojourn in each laboratory, the Public Health Service bacteriologist also carried out parallel procedures on routine samples of sea water and shellfish at each of the laboratories participating in the survey. The results of such parallel sets of tests served as check procedures on the results of each of the laboratories, and also as an important agent in coordinating the technical skill of the staffs and the results secured in the three collaborating laboratories.

(4) At certain intervals, large volumes of sea water were col-

lected at points representative of certain Bay areas. These large-volume samples, after thorough mixing, were divided and poured into four sterile containers. One of three such portions of the sea water was delivered respectively to each of the participating laboratories. The fourth portion was examined by the Public Health Service bacteriologist. Each of the agencies to whom such portions were submitted examined the water in a manner identical with the one used in the examination of the routine samples. The average time elapsing between collection and examination was about 5 hours.

It should be added at this point that the Public Health Service bacteriologist examined one such cross check sample of sea water in each of the participating laboratories. Such a procedure of checking afforded the opportunity to compare the results obtained by the technical personnel of the respectively collaborating laboratories with those secured by the Public Health Service bacteriologist under the conditions prevailing in each of the collaborating laboratories. The advantage of such a thorough and complete system of checking results is easily appreciated. The closeness of coordination and degree of accuracy secured by the three laboratories participating in this survey, and the inestimable value of the standardization secured by the above described system of collaboration and supervision leading to the faithful following of the outline of prescribed procedures can be seen in Table I.

(Insert Table I)

It will be observed that these results were, with few exceptions, quite good checks bearing in mind the deviations

TABLE I.

RESULTS OF QUADRUPLICATE PLANTINGS OF CHECK SAMPLES

May, 1941	Sample No.	Total Count per ml.				Coliforms per 100 ml.			
		Freeport	Highlands	N.Y.City	USPHS	Freeport	Highlands	N.Y.City	USPHS
6	18 N.J.	450	520	490	980	170	220	490	130
6	26 N.J.	-	720	1180	-	240	170	330	310
6	60 N.J.	75	52	256	120	49	46	17	33
13	A 12	15	59	65	60	170	920	330	310
13	A 25	170	-	360	250	400	3500	4900	5400
13	A 31	600	870	915	860	5400	3500	17,000	16,000
26	J 65	1250	640	1420	2260	13	13	≤ 23	23
26	J 85	2870	980	1220	2100	33	7.8	20	23
26	J 86	1480	750	1570	1580	11	49	18	6.8

≤ Equal to or less than.

which are to be expected from routine bacteriological analyses. There is apparently no consistent deviation from the general run of results on the part of any of the collaborating laboratories.

Sample Collection

Raritan Bay. For the purpose of sampling, the bay was divided into eight areas with ten to twenty sampling points in each area. Two sets of samples were usually taken from an area on a given day, one at ebb or flood slack water, and the other three hours earlier, or later, at the half tidal interval. The period of about two hours between sampling was utilized in general for the collection of shellfish samples. Sampling was so scheduled that the mid-sampling time of each run coincided with the calculated time of occurrence of the tidal condition which was being sampled. Each sampling run required about one hour. In analyzing the data, no attempt was made to correct for the deviation of the actual sampling time from the time of quarter tide as it rarely exceeded 1/2 hour for the first and last samples. The majority of samples were taken within 15-20 minutes of the estimated time of occurrence of the tidal condition. The following number of sets of samples were taken in the eight areas during the course of the survey.

Tide Conditions	Area							
	1	2	3	4	5	6	7	8
	Number of Sets of Samples							
Flood Slack	3	2	4	1	3	2	3	3
1/2 Ebb	2	2	3	3	3	4	4	4
Ebb Slack	3	2	3	3	3	3	3	3
1/2 Flood	2	2	4	1	3	2	4	2

The sampling points chosen were the ones used in these areas during previous surveys, although it was not possible to cover all of the points which had previously been used in the bay. The controlling factor was the number of samples which each laboratory could handle. The points selected for the collection of samples in this study are shown in Figure 5.

In the collection of samples from a given area, a sampling schedule was made and the estimated time of collection was entered upon the sample collecting card which also carried spaces for the recording of water temperature, water salinity, actual time of sample collection and other data such as wind direction and velocity and observed tide condition. The sampling times were computed for a boat speed of 10 knots for the New York State Conservation Department boat, and 7 knots for the New Jersey boat. Location of the points of sampling was largely done by lining up with fixed markers such as buoys, shore objects, etc., and by timing when running along a line of sampling points. This method, in general, gave good accuracy in the location of points, a major factor being, however, thorough familiarity of the sampling crew with the area to be sampled. Bad weather conditions reduced somewhat the number of runs which were made and also complicated the scheduling of runs, inasmuch as a uniform number of runs at each tide condition was desirable and lost runs at certain tide conditions were difficult to obtain at a later date. It is believed that although this sort of scheduling has the advantage of obtaining good definition of the swings of pollution with the tidal currents in addition to average values for the pollution at any given point, the difficulties of scheduling make some simpler method desirable, where only the average pollution at a given point is required. Such a method was reported by Miller(2) in his previous study of Raritan Bay.

Samples were taken at 5 foot depth throughout the bay with a sampler holding a single bacteriological sample bottle of about 250 ml. capacity. The New York State Conservation Department single rope sampler shown in Figure 2 was made of brass and

(Insert Figure 2)

consisted essentially of a frame holding the bacteriological bottles and a pivoted target which gripped the bottle cap. When lowered, the vane on the target arm tended to keep the bottle closed, but when given a slight jerk at the proper depth, pressure on the vane increased by the lever action of the pivoted arm opened the bottle allowing it to fill. The New Jersey State Department of Health sampler was a two rope single bottle sampler which utilized a ground brass cover plate for a stopper. The sampler was lowered to the desired depth and the bottle filled by pulling on the auxiliary rope. After filling, a spring forced the brass cover plate against the bottle and it was raised in closed position. To sterilize the bottle cover between collections, this sampler was kept in a strong chlorine solution and was rinsed in bay water at the sampling point before insertion of the bottle and collection of the sample. No serious objections were found to either the New York or New Jersey methods of sampling. Temperatures and salinities were taken from surface samples, the latter being hydrometer readings. Samples were transported by car to the laboratories in iced containers. The average time elapsing between collection and examination was about 5 hours with a maximum of about 7 hours, except for part of the inlet samples, referred to in the succeeding section. About half of these inlet samples were kept overnight on ice and examined the following morning.

Sampling of Inlets. Sampling of the four major inlets to Raritan Bay were made along lines shown in Figure 3. Sets of three to eight samples of a cross section at these inlets were taken at 7, 9, and 11 A.M., and 1, 3 and 5 P.M., the sampling starting at the hour mentioned. Samples were taken from boats except for Raritan River where they were taken from a low bridge. The sample collecting device used was the New York State Conservation Department single rope sampler, previously described.

(Insert Figure 3)

In determining the location of sampling points for the inlets, a cross section of the inlet was plotted along a line between prominent landmarks at the narrowest part, the cross section was divided into a number of equal areas and the sampling point located at the center of gravity of each of the equal areas, as shown for Rockaway Inlet in Figure 4. Three samples of the cross section were taken in each set for Raritan River and Arthur Kill, while five were taken at Rockaway Inlet and eight at the Narrows. For the latter two inlets samples were taken at each point at 1/3 and 2/3 of the average depth, or, alternately at eight and twenty-two foot depths and at twenty and sixty foot

(Insert Figure 4)

depths, respectively. Location of points along the sampling line by the sampling boat was accomplished largely by timing the boat. Little difficulty was encountered except that the sampler did not always work at the sixty foot depth in the Narrows. It is believed, however, that fairly good distribution of sampling was obtained and that the means of these samples represent fairly accurately the mean composition of the waters flowing through the various inlets.

Collection of Shellfish Samples. In order to get good distribution of hard clam samples from the bay, it was originally planned to have samples collected by tongs from the sampling boat alternately from two of the four quarters of the area being sampled, if shellfish could be found. This was done for part of the samples, and others were collected from the boats of nearby clammers. Hard clams were absent or scarce in fairly large areas in the bay and in some places could not be obtained due to lack of equipment suitable for clamming at the depths encountered. Hand tongs could be used up to about 10 feet and hand rakes up to 15 feet or so, but at greater depths it was necessary to use a drag rake if samples were to be obtained.

Sources and Amounts of Pollution of the Lower Bay.

In determining sources of pollution of Raritan Bay, time did not permit the location and enumeration of sources on the various tributary waters. The total amount of such pollution was, however, measured through several tidal cycles and, it is believed, the information obtained in this manner is sufficient for the purposes of this survey. Sources of pollution directly tributary to the bay are listed in Table II, together with the contributing drainage areas, the method of sewage treatment, population served and key letters referring to their locations on Figure 3. Where the discharge is into a tributary stream, the location of the plant is not shown on the map.

(Insert Table II)

It will be observed from Table II and Figure 3 that all sewage, except for a slight amount discharging into the Navesink River and the Tottenville sewers located at the mouth of Arthur Kill, is given a minimum treatment, *chlorination. The two most important plants with respect to the effect of their operation upon the bacteriological quality of the water in the bay are the Oakwood Beach and South Beach plants on Staton Island. Operational data and the results of analyses of effluents at these plants have been furnished by the Department of Public Works, New York City, and these data are shown in Table III. The Oakwood Beach plant had somewhat the better effluent, but considering that a residual of 1,000 coli per ml. the maximum residual, represents removals of about 99.8 per cent, both plants presented satisfactory operation, considering the nature of the receiving waters and dilution factors. It is interesting to note that only one sample was picked up on the bay survey, which indicated an excessive amount of pollution in the vicinity of the outfalls of these plants.

(Insert Table III)

(*) The dental works H, Figure 3, discharges a small amount of sewage, untreated.

TABLE II

Sources of Pollution of Raritan Bay

Section	Drainage Area Sq.Mi.	Description	Source of Pollution	Map Desig.	Pop. Thous.	*Treatment	Source of Information
1	1	Sandy Hook Shore	None	-	-	-	a
2	126	Navesink-Shrewsbury Rivers	Fort Monmouth (N.J.)	-	-	Sec.-Chlor.	a
			N.Long Branch (N.J.)	-	-	Prim.	a
			Branchport "	-	-	"	a
			Rumson "	-	2.1	"	a
			Red Bank "	-	11.6	Prim.-Chlor.	a
3	31	Atlantic Highlands to Keyport Shore	Atlantic Highlands, N.J.	A	2.0	Prim.-Chlor.	a
			Keansburg, N. J.	B	2.1	Chlor.	
4	15	Matawan Creek	Keyport, N. J.	C	4.9	Prim.-Chlor.	a
			Matawan Borough, N.J.	-	2.3	Prim.-Chlor.	a
5	11	Cheesequake Creek plus shoreline from Keyport to Victory Bridge	South Amboy, N.J.	D	8.5	Prim.-Chlor.	a
6	1,105	Victory Bridge Raritan River	Measured				
7	—	Perth Amboy	Perth Amboy, N. J.	E	43.5	Prim.-Chlor.	a
8	1,370	Arthur Kill	Measured				
9	19	Staten Island Shore (Tottenville to Narrows)	Tottenville (N.Y.City)	F	20.0	Untreated	c - e
			Mt. Loretto Home "	G	1.5	Chlor.	b
			Dental Works "	H	Small	Untreated	c
			Richmond Hospital "	I	0.1	Prim.-Chlor. Apr.-Sept.	b
			St. Josephs Home "	J		Prim.-Chlor.	b
			Assoc. for Poor "	K		" "	d
			Oakwood Beach "	L	14.0	Chlor.	d
			Cromwell Avenue "	M	20.0	"	d
10	14,400	Narrows	Measured				

Note: Arthur Kill, above Fort Wadsworth on Narrows, Brooklyn shore and Gravesend Bay, badly polluted, with numerous sewers discharging untreated.

* Prim. = Primary treatment; Sec. = Primary + secondary treatment; Chlor. = Chlorination.

Source of Information:
(a) New Jersey State Dept.of Health, (b) Interstate San.Comm.Ann. Report (1940), (c) Shore Survey Interstate San. Comm.
(d) New York City Dept. of Public Works, (e) Interstate San. Comm. Report (1937).

TABLE III

Operational data on New York City Cromwell Avenue and Oakwood Beach sewage treatment plants during survey.

Date	Cromwell Avenue				Oakwood Beach			
	Daily Flow M.G.D.	Chlorine Lbs. per day	37° Count per ml.	Coli per ml.	Daily Flow M.G.D.	Chlorine Lbs. per day	37° Count per ml.	Coli per ml.
Apr. 3	2.9	162	84	1	2.2	99	5	0
7	4.1	183	50	1	4.0	139	17	0
10	4.1	195	38	10	3.0	120	20	1
14	3.6	135	56	1	2.7	110	0	0
17	3.2	150	95	1	2.5	104	10	0
21	2.9	163	116	1	2.4	93	75,000	1000
24	2.8	160	40	0	2.3	103	59	0
28	2.9	164	480	1	2.3	105	12	0
May 1	3.1	184	2300	1000	2.2	100	38	0
5	3.3	180	18	1	2.4	111	7	0
8	3.0	164	460	100	2.5	111	8	0
12	3.1	169	109	1	2.5	118	13	0
15	2.7	162	3	0	2.3	100	3	0
19	2.7	158	120	100	2.3	102	14	0
22	2.5	128	5000	1000	2.3	108	160	1
26	2.4	152	500	100	2.1	99	18	0
29	2.4	157	8000	100	2.1	106	400	1
June 2	2.3	138	20	0	2.1	110	37	0
5	2.4	167	160	100	2.7	128	15	0
9	2.3	162	30	1	2.4	117	16	0
12	2.8	154	250	1	2.1	111	7	1
16	3.5	180	25	10	2.4	133	19	1
19	3.1	167	100	10	2.0	124	16	0
23	3.0	183	285	100	2.4	121	10	1
26	3.0	248	1700	1000	2.3	114	9	0
30	3.5	310	400	10	2.3	117	170	10
Average	3.0	174	786	140	2.4	112	2930	39

In Table IV are shown data for several New Jersey sewage treatment plants as furnished by the New Jersey State Department of Health. It will be observed that the residual level of bacteria in the effluents was quite satisfactory at each of these plants. In addition, a factor of safety is provided in the present requirement which prohibits the taking of shellfish within a minimum of 1/4 mile of the shore.

(Insert Table IV)

Pollution at the point of Tottenville, in Section 9 (point F on Figure 3) was estimated to be from a contributing population of 20,000 by Hess(3) in 1937. This pollution, while partially included in the analyses of Arthur Kill waters, probably adds somewhat to the quantitative figures for Arthur Kill due to its proximity to the approved shellfish areas.

Pollution of Tributary Waters.

The mean values* obtained from analyses of waters of the four inlets into Raritan Bay are given in Table V. Coliform densities were highest in the Narrows, averaging 10,600 per 100 ml., second highest at Rockaway Inlet with 2350 per ml. and both Raritan River with 396 and Arthur Kill with 345 per 100 ml. were considerably lower. Figures for the Narrows were about half those given in a report by Greeley, Marston and Phelps(4) for 1938 routine sampling by the New York City Department of Public Works. A single sampling point is shown on their map, however,

(Insert Table V)

(*) The individual coliform results are given in Table 1, Appendix I.

TABLE IV.

Operational data on five New Jersey sewage treatment plants.

Date 1941	Plant	No. Obser.	Flow m.g.d.	Chlorine Lbs. per day	Residual Chlorine p.p.m.	37° Bacteria per ml.	Coliforms per ml.
May 27	Atlantic Highlands	5	0.22	40	1.3	12	≤.2
27	Perth Amboy	9	4.0	248	0.12	Not made	1.2
27	South Amboy	9	0.6	50	0.25	10,000*	11.
27	Keyport	5	0.5	40	0.10	84	2.
27	Keansburg	5	1.0	75	0.0	91,000	16.

(*) High due to the effect of a single sample.

TABLE V.

Results of analyses of inlet waters of Raritan Bay.

Mean Values

Date 1941	°F. Water Temp.	Per cent *Salinity	Coliform, MPN/100 ml.	Bacteria/ml. Agar
Rockaway Inlet				
Apr. 28	52	2.54	2200	217
May 19	58	2.62	1700	132
June 9	59		3160	202
Average	56	2.58	2350	184
Narrows				
May 12	54	2.31	12,100	1400
May 26	59	2.31	9,100	1030
June 16	67		8,560	2570
June 30	66		12,500	790
Average	62	2.31	10,600	1450
Raritan River				
May 6	57	1.58	629	10,500
May 20	60	1.83	148	30,200
June 2	60		442	106,000
June 23	72		364	17,800
Average	62	1.70	396	41,100
Arthur Kill				
May 5	58	1.90	708	1700
May 20	60	2.24	233	2590
June 2	58		202	5070
June 23	71		236	3080
Average	62	2.07	345	3110

(*) Percent chlorides as sodium chloride.

and it is not believed the data they obtained are strictly comparable to that obtained in this survey. It is believed that the similar values obtained in the figures for Arthur Kill and Raritan River are partially the result of mixing even though the 37° counts are consistently much higher for Raritan River. This impression is obtained by a study of the variation throughout the tidal cycle of the values for 37° counts and coliforms. The mean of all values for Raritan River and Arthur Kill, considering tidal times, are given in Table VI.

(Insert Table VI)

It will be observed that the maximum 37° plate count in Raritan River occurs 10 hours after the sampling time nearest ebb slack or during the latter part of the ebb current, representing probably, water largely of Raritan River origin. From this high value, there is a steady decrease for the next 6 hours during which time the flood waters from both Arthur Kill and Raritan River return. Arthur Kill 37° counts, on the other hand, show a maximum 4 hours after the nearest ebb slack when receiving mixed Raritan Bay waters at the same time that a minimum is present in Raritan River. Figures for coliforms are much more nearly equal throughout, showing a minimum in both Arthur Kill and Raritan River occurring 4 hours after the sampling time nearest ebb slack along with the return of cleaner Raritan Bay water into these tributaries.

The period covered by this survey was one of quite low land water discharge and it is desirable that the effect of heavy

TABLE VI

Variation of bacterial results in Raritan River and Arthur Kill with tidal time

Sampling Time	37° Count per ml.		Coliforms per 100 ml.	
	Raritan River	Arthur Kill	Raritan River	Arthur Kill
Sampling time nearest ebb slack	33,100	2,780	360	424
" 2 hours later	28,100	2,940	342	251
" 4 " "	11,500	4,940	194	170
" 6 " "	33,000	2,260	378	538
" 8 " "	58,700	2,600	660	244
" 10 " "	82,000	3,140	440	442
Average	41,100	3,110	396	345

land water discharges be evaluated, if possible. The work of Phelps and Velz(1) points the way to a possible method of analysis of these conditions. These authors list the major effects operating upon bay waters as:

1. Land water runoff,
2. Oscillation of tides,
3. Up flow of sea water, which varies according to land water discharge.

These are, of course, in addition to the processes of natural purification. The constant swing of water under tidal action past fixed sources of pollution discharging continuously, together with mixing which occurs naturally due to wind and boat action suggest that this tidal prism may be considered as a completely mixed body of water subject to displacement seaward due to the action of both up flowing sea water and down flowing land water discharge. Such mixing formulations have been used by Phelps and Velz(1, p.139) in analyzing dissolved oxygen conditions in New York harbor. If complete mixing is assumed, the problem then may be considered as a continuous flow mixing tank and the methods used by MacMullen and Weber(5) for chemical reaction tanks and that suggested by Kohr(6) as a method of analysis for relatively short activated sludge aeration tanks would apply. These authors have shown detention in such tanks to be dominated by mixing rather than the displacement factor. According to the analysis presented in these articles, when the contents of a well mixed tank are subject to the action of a monomolecular reaction (such as the rates of bacterial decreases) and using the terminology of Kohr(6), the ratio of the effluent to the influent is:

$$\frac{RY}{I} = \frac{R}{R + K^1}$$

when equilibrium is reached, in which

R = the reciprocal of the displacement time in days,

I = daily addition of coliform, and

*K^1 = constant defining the logarithmic (Naperian) rate of decrease of bacteria with time in days.

The daily increment of bacteria into the system would be I for this equation and Y, the total bacteria in the system.

In the present study, knowing the volume of water in the oscillating tidal prism and the mean coliform density of this water, the value of Y can be computed. The value of R can be computed as the volume of the tidal prism divided by the daily discharge of both land water and sea water up flow. The average per capita contribution of coliforms has been estimated by Hoskins(7) to be 249 billions per capita per day, which makes possible the estimation of the contributing population, or use of this figure to check the calculations based on various assumptions. It should be noted, however, that Hoskins' figures were derived on the basis of fresh water measurements. Furthermore, the basic data regarding tidal flows are quite crude, even to the extent that the net direction of flow in the East River is disputed. The figures used are, however, believed to be the best data available.

(*) If y = bacteria present at time t, and b equals bacteria present at zero time, then $y = b\,10^{-Kt}$, where K, a constant varying largely with temperature, $= \frac{K^1}{2.303}$. Then $y = b\,e^{-K^1 t}$, using Naperian logs.

Calculations Based on Complete Mixing Within The Tidal Prism.

The land water discharges during the period of the survey have been computed from discharges furnished by the U. S. Geological Survey. The method used was to take the discharge of the major streams at the lowest measured point in their drainage basin, adding to this a computed c.f.s. per square mile for the residual drainage area based on several small and relatively uncontrolled streams, i.e., the Walkill near Gardiner, N. Y., Swimming River near Red Bank, N. J., and the Millstone at Blackwell Mills, N. J. Discharges during the period of May and June, 1941, from these drainage areas, are given in Table VII.

(Insert Table VII)

New sea water entering the Narrows, which along with land water discharge, would tend to displace the tidal prism seaward was taken from Phelps and Velz curve.(1, p.143) In lieu of calculations more applicable to the conditions of Arthur Kill and Raritan River, the Phelps and Velz figures for the Narrows were re-computed on a basis of the ratio of sea water up-flow to land water discharge at a given c.f.s. per square mile discharge, the figures, as used, being:

c.f.s. land water per square mile at Narrows	Ratio, new sea water to land water
0.35	1.57
0.69	2.08
1.04	1.94
1.39	1.69
2.08	1.17
2.78	0.78
3.47	0.56
4.16	0.42
5.55	0.28

TABLE VII.

Land water discharges into Raritan Bay.

Stream & Point of Measurement	Drainage Area Sq. Mi.	C.F.S. May-June, 1941	Remarks
Narrows – 14,400 sq. mile drainage area			
Hudson at Mechanicsville	4500	2272	
Mohawk at Cohoes	3456	1491	
Sum	7956	3763	
Newark Bay – Arthur Kill, 1370 sq. mile drainage area			
Passaic at Patterson	785	352	
Hackensack at New Milford	113	26	
Sum	898	378	
Raritan River – 1105 sq. mile drainage area			
Raritan at Manville	490	216	
Streams used to determine discharge from residual drainage areas			
Millstone at Blackwell Mills	258	182	Mean c.f.s. per sq. mi. = .68 May – June, 1941
Swimming River near Red Bank	48.5	45	
Walkill near Gardiner	711	290	

While the actual values may vary somewhat from these figures, the deviations would not, it is believed, greatly affect the accuracy of the calculations made. In addition to the land water discharge and sea water upflow, there are various other hydraulic phenomena for which it is necessary to assume values based upon more or less accurately determined figures. The net flow from Newark Bay to Upper Bay was taken as 200,000,000 c.f. per day and through the Harlem River to the Hudson River as 60,000,000 c.f. per day, the latter being a rough average of the values of Parsons, 35 million, and Robinson(8, p.94), 90 million, c.f. per day. Flow from the East River to the Upper Bay is taken as 900 million c.f. per day. All of these figures have been compiled as a W.P.A. project by the Interstate Sanitation Commission(8) from various sources. The tidal prism of 12 billion c.f. oscillating through the Narrows is that used by Phelps and Velz(1) and the value of 314 million c.f. for Arthur Kill was obtained from the average ebb and flow figures as given in the 1912 Report of the Metropolitan Sewerage Commission.(9)

Calculations based on: (1) coliform data presented in Table V, (2) assumed complete mixing of discharged sewage with the tidal prism and (3) the hydraulic data from various sources, are as follows:

Narrows: 12 billion c.f. x 10,600 coliforms per 100 ml. = 3.6×10^{16}

Total in tidal prism
Millions of c.f.

200 - Kill Van Kull
60 - Harlem River
900 - East River
2040 - Land water discharge plus sea water upflow
______
3200 - Total

From Table V

3763 c.f. + .68 x 6444 = 8163
Total land water discharge at Narrows, plus 1.9 times as much sea water = 23,700 c.f.s.
= 2.04 billions of cu. ft. per day, land plus sea water upflow

$\frac{12}{3.20}$ = 3.75 days displacement time for prism.

$$R = \frac{1}{3.75} = .267 \quad \text{or} \quad \frac{\text{Ratio of Effluent}}{\text{Influent}} = \frac{RY}{I} = \frac{R}{R + K}$$

or, if I = influent = total daily added coliforms
Y = total bacteria present in the tidal prism

$$\text{then} \quad \frac{.267 \times 3.6 \times 10^{16}}{I} = \frac{.267}{.267 + 1.2 \times 2.303}$$

(The value of 1.2 for K is from data presented in a later section of the paper and corresponds to an average temperature of 17°C.)

$$I = 3.6 \times 10^{16}\left(1 + \frac{1.2 \times 2.303}{.267}\right)$$

$$= 3.6 \times 10^{16} \times 10.4 = 3.73 \times 10^{17}$$

The population equivalent of such a daily addition to the tidal prism, using Hoskins(7) figure of 249 billions per day would be

$$\frac{3.73 \times 10^{17}}{2.49 \times 10^{11}} = 1{,}500{,}000 \text{ persons.}$$

This compares with approximately 2.5 millions of persons for the summary of Phelps and Velz 1930 population figures for total contributing population of the Upper Bay – Narrows system excluding the East and Hudson Rivers. However, the tidal prism occupies only about 63 per cent of the mean tide level volume of 17,558 millions of cu. ft. given by Greeley, Marston and Phelps.(4,p.27) Contributions to the oscillating tidal prism from waters beyond this limit of 63 per cent of the Upper Bay, would at time of low land water discharge be relatively small due to the long detention periods in waters receiving the sewage directly.

The average figures obtained for coliforms in

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the Narrows, 10,600 per 100 ml., are about half of the 23,000 per 100 ml. given by Greeley, Marston and Phelps(4, p.47) for 1938. There are, of course, many possible sources of error in such computations but the general order of magnitude is correct and the picture to be obtained by the assumption of complete mixing with high rates of decrease is quite important. It means that the total coliforms present in the tidal prism at a given time, compared to the daily contribution are $\frac{3.6 \times 10^{16}}{3.73 \times 10^{17}} =$ 9.7 per cent. This is understandable when one considers the rapid rates of purification K = 1.2 or 90 per cent decrease in about 20 hours.

Arthur Kill.

In calculating the total and contributing populations to the tidal prism passing Perth Amboy in Arthur Kill it is necessary to make some division of the land water which leaves Newark Bay through Kill Van Kull. Salinity measurements averaging 53 per cent have been reported during July, August and September 1938, by the Interstate Sanitation Commission.(10, p.58) Of the 200 million c.f. discharge through Kill Van Kull, the land water would amount to 47 per cent or 95 million cu. ft. During this period the land water discharge into Newark Bay averaged 3190 c.f.s. or 276 million c.f. per day. Arthur Kill, therefore, took approximately 70 per cent of the land water discharge and Kill Van Kull 30 per cent of that coming into Newark Bay. This ratio has been assumed as constant there being, in addition, drainage into Arthur Kill from about 167 sq. miles which is not included in the Newark Bay receipts.

The mean discharge into Arthur Kill, as given in Table VII for May and June, 1941, would therefore be 70 per cent of the sum of 378 c.f.s. plus 207 or 409 c.f.s. to which should be added 113 c.f.s. tributary directly to Arthur Kill giving a total of 522 c.f.s. for the land water discharge. If 1.6 be taken as the ratio of sea water upflow to land water discharge, a total of 1357 c.f.s. total displacement is obtained or 117 millions of cu. ft. per day, and the detention period for the tidal prism $\frac{314}{117}$ = 2.68 days, R = .373.

The average of 345 coliforms per 100 ml. in the tidal prism gives a total of 3.07×10^{13} coliforms.

The estimated total daily addition would, therefore, amount 2.55×10^{14} = 1000 population equivalents contributed.

This seems quite small and is unexpectedly low. However, the figure of 345 per 100 ml. coliforms also seems low and it is believed that part of this may be ascribed to mixing of the waters of Raritan River with those of Arthur Kill. This would result in a value somewhat high for the Raritan River and low for Arthur Kill as there is no doubt that Arthur Kill receives considerably more coliforms from sewage pollution than Raritan River. Raritan River is cleaned up for a considerable distance upstream, making it unlikely that any considerable amount of pollution reaches Perth Amboy from upstream.

Raritan River.

Although stream flow data for the Raritan River are good, it is necessary to compute the volume of the tidal prism inasmuch as no figures for this could be found. Values are available for the maximum velocity of current at mean high and low tide from current tables published annually by the U. S. Coast and Geodetic Survey. This is given as 1.5 knots per hour at strength of current or, using .637 as the ratio of average to maximum for a cosine wave, an average velocity of .96 knots per hour. The cross sectional area for mean tide level at Victory Bridge is roughly 27,200 sq. feet, which for a half tidal cycle would give roughly one billion cu. ft. Using a factor of 0.85 as the ratio of average to surface current, the volume of the tidal prism would be 850 million cu. ft.

The estimated average discharge of the Raritan during the period of this survey was 636 c.f.s. to which should be added 1.6 times as much sea water giving a total daily displacement volume of 143 million cu. ft., a displacement period of 5.9 days or, R = 0.17. With a K of 1.2, these figures give a total daily accretion of 16.4×10^{14} coliforms for the tidal prism, corresponding to an equivalent population of 6000 persons.

While it is possible that the equivalent population may be as much as 6000 or more, it seems likely that a considerable portion of this pollution is derived by mixing with the waters from Arthur Kill and the return of such a mixture on the flood tide.

Calculation of the Effect of Inlet Waters on Upper Raritan Bay

In an attempt to check both the assumed rates of decrease of coliforms of K = 1.2 and the effect of inlet pollution under a different set of conditions of river discharge, calculations were made of the distance to which pollution would extend into the bay. In the upper end of Raritan Bay in Figure 5 areshown

(Insert Figure 5)

4 sections, A, B, C, and D, for which cross sectional areas were computed at mean tide level, as follows:

A - 111,500 sq. ft. area
B - 142,300 " " "
C - 198,100 " " "
D - 289,300 " " "

Distances from the center of gravity of the cross sections are A - B = 3500 ft., B - C = 6000 ft., C - D = 11,300 ft.

The center of the sum of the two tidal prisms of 850 + 314 million cu. ft. from both Arthur Kill and Raritan River would occupy at extreme ebb a position along the line of Section B. Inasmuch as 6 hours would be required to reach this position from the inlets, the mean coliform density would be expected to be about 50 per cent of the weighted densities in Arthur Kill and Raritan River, or about 190 coliforms per 100 ml. This approximates the mean value of 209, in Table VIII, for point 30 of Area 8, which is slightly beyond Section B. The maximum extent of the tidal prism at extreme ebb would be about half of the volume between Sections B and C and the displacement of 260 million cu. ft. per day would theoretically require four days for the center of the tidal prism to travel from B to C. During those four days, purification would amount to more than

99.99 per cent at K = 1.2. Actually, stray currents, increased salt water intrusion and possibly a lowered rate of decrease of bacteria combine to prevent such limits being reached, although values which would represent decreases of 99 per cent from the inlet coliform content are not unusual for bay waters somewhat further out.

A similar set of calculations have been made on a series of analyses of Raritan Bay waters collected during April and June, 1940, by the New York State Conservation Department Laboratory at Freeport, N. Y. Lines of equal coliform density derived from plotted figures for this survey are shown in Figure 5.

Discharges of the Hackensack and Passaic Rivers during those two months averaged 3246 c.f.s. and for the Millstone and Swimming Rivers 2.49 c.f.s. per sq. mile. Temperatures were about the same and the same K value, 1.2, was used. The Raritan River discharge at Manville averaged 1565 c.f.s. Using the same tidal prism volumes and contributing populations, the mean coliform densities were computed to be: Raritan River prism = 3180 coliforms per 100 ml., Arthur Kill prism = 1340 per 100 ml., or a weighted mean value of 2680 per 100 ml. for the combined tidal prism. The value at Section B should be one-half of that or 1340 per 100 ml. Actually as shown in Figure 5, the 1000 coliform line fell slightly short of Section B and a single average value of 597 was observed approximately along the line of Section B. These calculations, while admittedly quite rough, do serve to emphasize the large effect of increased discharges and enable the determination, with reasonable accuracy, of the source of the high values for coliforms which were observed during the 1940 survey by the New York State Conservation Department.

Results of the Survey of Raritan Bay Waters.

Temperatures. The results of temperature observations during this survey, and during previous surveys made by the New York State Conservation Department, have been plotted in Figure 6 along with the mean normal air temperature for New York City

(Insert Figure 6)

as published in the annual meteorological summaries. Each plotted point represents the average of a considerable number of observations made during a single sampling run. It will be observed that bay temperatures lag behind average air temperatures by about 5 - 10 days, but show a peak several degrees higher than normal air temperatures and do not fall as low as the latter during the winter.

Coliform results.

As previously described in the section under Sample Collection, two sampling runs were made daily to pick up, in the area being sampled, two of the four quarter tide conditions, high, half ebb, low and half flood. The coliform results have been summarized* for these four conditions and are presented for each station along with the mean for the four conditions, in Table VIII.

(Insert Table VIII)

(*) The individual coliform results are given in Table 2, Appendix I.

TABLE VIII.

Average coliform concentrations per 100 ml. at each sampling point in Raritan Bay.

Station	High	1/2 Ebb	Low	1/2 Flood	Mean
Area 1					
89	81	280	49	40	112
91	88	500	104	233	231
93	87	295	177	64	156
95	64.5	28.4	19.4	360	118
96	29.6	87	44	153	78.4
98	75	124	48	56	75.8
100	123	136	55	72	96.5
105	58	12.5	22.8	143	59.1
109	28.8	26.5	22	29.9	26.8
110	25.2	19.9	53.4	22.0	30.1
Area 2					
33	8270	2107	13.8	1995	3100
35	480	644	1045	2950	1280
37	-	2400	-	-	-
44	94	497	715	515	455
46	170	523	1445	2225	1091
48	4775	2217	21	285	1820
68	89.5	648	34.5	78.5	213
70	124	757	1995	895	945
72	138	463	2400	390	848
79	230	410	130	90	218
81	-	540	-	-	-
83	76.5	294	73.5	230	168
Area 3					
27	53.8	18.1	51.7	35.5	39.8
28	-	46	-	-	-
29	20.2	60.5	21.3	33.5	33.9
30	227	39.9	9.2	21.2	86.8
31	970	48.7	6.5	395	355
62	11.9	34.8	11.0	45.7	25.8
63	18.3	21.0	13.9	33.4	21.6
64	37.7	28.5	3.6	29.5	24.8
65	12.6	17.8	9.1	30.1	17.4
66	-	130	-	-	-
86	38.3	18.9	22.9	87.8	42.0
85	129	84.9	32.2	22.4	67.1

TABLE VIII (Continued)

Station	High	1/2 Ebb	Low	1/2 Flood	Mean
Area 4					
18	* 13	49	140	* 170	93.0
20	* 220	94	190	* 130	158
21	* 170	163	107	* 240	170
22	* 79	80.7	137	* 330	157
24	* 7.8	45.3	201	* 170	106
26	* 79	19.3	73.3	* 130	75.4
55	* 17	11.3	64.7	* 23	29
57	* 7.8	28.7	134	* 110	70.1
59	* 23	53.7	74	* 130	70.2
60	* 7.8	23.5	19.4	* 110	41.4
Area 5					
12	106	1647	9470	210	2360
14	56.1	1143	1577	145	730
15	3230	910	687	2397	1810
16	1763	2850	346	3860	2330
17	1215	1100	1160	1410	1220
18	190	2280	2700	570	1435
25	867	4170	10900	2200	4530
26	652	2360	540	3760	1950
27	910	821	291	3950	1690
28	896	224	584	1244	737
29	2150	443	723	3400	1680
30	1110	923	3330	2680	2010
31	3560	4800	11500	3030	5720
46	1170	6400	12400	3160	5780
Area 6					
2	81.5	88.9	137	4600	1230
6	46.5	104	33.4	625	202
7	390	65.2	28.0	515	250
8	1760	83.8	31.7	140	504
9	1674	235	20.7	2490	1100
10	640	1930	147	1365	1020
11	1815	5000	70	1715	2150
12	1220	938	38.3	1015	803
13	400	1120	50.5	120	423
14	655	422	13.9	25	279
53	558	914	17.3	76.5	391
54	404	1090	26	418	484
55	268	1230	21.3	1705	806
56	674	275	7.7	924	470
57	661	277	50.3	94.5	271
58	397	158	24.3	46	121
73	40.6	28.6	4.4	35	27.2
74	169	103	5.7	211	122
75	420	97	25.7	230	193
76	1090	61.7	21	104	319

* Single Observations

TABLE VIII (Continued)

Station	High	1/2 Ebb	Low	1/2 Flood	Mean
			Area 7		
15	22.7	48.5	48.3	35.2	38.7
16	8.7	31.8	33.3	14.2	22.0
17	16.3	16.4	55.6	16.0	26.1
18	9.0	24.3	63.7	33.3	32.6
19	5.1	22.8	80.3	23.2	32.8
38	3.7	103.	241.	44.2	98.0
39	10.7	86.3	9.8	66.4	43.3
40	6.7	30.5	24.6	21.7	20.9
41	7.9	58.1	23.	38.8	32.0
49	3.4	36.1	35.	26.7	25.3
50	10.6	30.3	45.3	21.1	26.8
51	10.5	27.1	36.6	31.9	26.5
52	31.3	73.9	41.7	31.1	44.5
59	155.	188.	25.	81.5	112.
60	12.6	178.	28.8	107.	81.6
61	12.5	235.	17.7	110.	93.8
62	4.9	245.	34.7	35.7	80.1
63	5.6	168.	11.4	17.8	50.7
64	6.9	81.1	69.2	23.2	45.1
66	24.8	136.	107.	14.4	70.5
			Area 8		
20	10.9	28.2	44.3	79.	40.6
21	7.6	139.	49.	49.	61.2
22	11.6	126.	193.	81.5	103.
23	28.	138.	113.	79.5	89.6
24	34.3	235.	270.	120.	165.
30	45.3	165.	397.	230.	209.
32	60.7	173.	393.	51.	169.
34	6.4	28.	86.	17.5	34.5
35	10.	44.5	45.	20.4	30.0
36	83.3	85.2	324.	172.	166.
37	60.7	30.5	102.	172.	91.3
42	31.3	20.	35.	13.	24.8
43	10.8	53.8	31.7	33.	32.3
44	4.4	40.	206.	15.4	66.4
45	41.7	197.	343.	66.5	162.
46	4.8	62.8	123.	46.5	59.3
47	10.6	61.2	106.	28.	51.4
48	19.7	20.7	43.	41.5	31.2

The data given in Table VIII are plotted in Figures 7 to 11 and lines of equal coliform density are drawn on these

(Insert Figures 7 to 11 inclusive)

maps to facilitate comparison. Areas showing an isolated depression of the coliform content, completely surrounded by water of higher coliform content are shown by a dotted line. Lines are drawn for 10,000, 5,000, 1,000, 500, 100, 50, 10 and 5 coliforms per 100 ml. A somewhat more uniform spacing of lines can be obtained by using equal logarithmic intervals for the lines, i.e., using 3.2, 32, 320, etc., as can be seen in Figure 5, instead of 5, 50 and 500 lines, but the latter are probably more easily read in general.

In Figure 7, at high tide, the area off Sandy Hook shows the maximum penetration of unpolluted sea water into the bay pushing the area exceeding 1000 coliforms up over areas 5 and 6. At the upper end of the bay, practically all of areas 4 and 8 are under 50 coliforms per 100 ml.

In Figure 8 which shows conditions at half ebb tide, polluted Narrows waters are again spreading over area 2 and the return of 5,000+ coliform water can be seen at the upper end of area 5. Raritan River and Arthur Kill water can be seen pushing into areas 4 and 8. The effect of currents can be seen over these latter areas as the lines of equal coliform content bulge sharply to the east along the dividing line between areas 4 and 8, while the cleaner mid-bay water extends further west along both shores. Current borne bulges are also apparent along the face of the Narrows pollution "tongue" in areas 6 and 7. Sandy Hook Bay proper is apparently affected largely by Narrows water as the coliform lines decrease as one goes further into the bay.

At low tide, Figure 9, the maximum extension of polluted waters from the various inlets can be observed. An area of 10,000 plus coliform water has moved into area 5 from the Narrows and the extension of Narrows pollution into area 2 covers more than half of this area with 500 plus coliform water. Some slight pollution of Sandy Hook Bay with Navesink River water is indicated by the area of low coliform content in the middle section with higher values in both inner and outer portions of the bay. At its maximum extension, 100 plus coliform water from Raritan River and Arthur Kill covers most of areas 4 and 8. The central area of relatively good water is quite evident, with the averages at two stations showing less than 5 coliforms per 100 ml.

Half flood conditions, shown in Figure 10, are in general similar to half ebb conditions shown in Figure 8. Pollution from the Narrows is shown being pushed toward Staten Island by clean sea water. The position of the coliform lines over areas 4 and 8 would indicate that inflowing currents tend to move directly across the bay and impinge upon the Staten Island shore, with little movement of the water in area 4, or possibly even a further movement eastward. It will be noted that in none of the tidal conditions indicated is there much evidence of outward extension of any localized shore pollution.

Most sampling points have been located more than 1/4 mile from shore due to shallow water encountered at low tide. This does not mean that beach areas are always unpolluted, however, but does indicate that such pollution is not evident 1/4 to 1/2 mile off shore. The general rule of maintaining closed areas within 1/4 mile (or more) of shore, is regarded as an excellent safeguard against localized pollution which undoubtedly occurs quite frequently.

Average coliform densities for the entire period of the survey are shown in Figure 11, along with the present areas which are open for the taking of clams. As will be observed, both ends of the present open areas in New York are "crowded" by water which averaged over 100 coliforms per 100 ml. during the period of this survey. Pollution of practically the entire New York open area during periods of high land water discharge, by water exceeding 100 coliforms per 100 ml. is indicated by the figures for the New York State Conservation Department survey of 1940 and is shown in Figure 5. The basis for such an extension of pollution during periods of wet weather has been theoretically confirmed. There is reason to believe that a similar extension of coliform lines occurs at the upper end of the New Jersey side of the bay, and that a further general extension of Narrows pollution toward the New Jersey shore also occurs during wet weather. The coliform lines averaging 100 per 100 ml. or greater on the New Jersey side of the bay cover all of area 2, part of area 1 and include a corner of area 3, while the present closed area in New Jersey due to Narrows dominated pollution extends from the point of Sandy Hook diagonally to about sampling point 14 in area 6.

The excellent agreement between laboratory data obtained from the New York State laboratory at Freeport and the New Jersey State laboratory at Highlands is quite well proven by the general correspondence between lines of equal coliform densities. These lines cross the state boundary repeatedly without appreciable jogs and the general trends of pollution are, in most instances, easily understandable in terms of known physical factors which affect the movements of bay waters.

Shellfish Studies

As discussed in the section under Sample Collection, batches of clams were dug or taken from clammers' boats in all areas of the bay where hard clams were available. Some idea of the nature of clamming operations in the bay can be obtained from Figure 12, which shows a group of clam diggers at work. Figure 13 shows the type of hand rake used for digging at this location.

(Insert Figures 12 and 13)

The coliform densities of the water overlying clam sample positions were obtained by plotting the location of each individual hard clam sample on Figure 11, the map of average water coliform densities and estimating the average coliform density of the water at that location. This method gave, it is believed, the most representative value obtainable for the comparison of water and clam coliform densities. The data for clams were averaged by areas of the bay, inasmuch as these showed some significant differences. While all analyses are too bulky to include in this report, the analyses from area 2, 10 in number, and those from area 3, 12 in number, are included in Table IX to give some idea of the variations encountered in the base data.

(Insert Table IX)

In summarizing the data, uniform M.P.N. values of 15 were assigned to clam coliform M.P.N. values of ≤ 23. This was done inasmuch as there were quite a few of these indeterminate values, most of which checked the general order of magnitude of the water coliform densities and the effect of variations from this assumed figure of 15 upon the geometric averages would undoubtedly be quite small.

It will be observed in Table IX that the difference in averages of coliforms for water and clams in area 2 as compared to area 3 are quite well borne out by the results on different sampling days and are seemingly consistent. The average M.P.N. values of clams and overlying waters for seven of the eight areas are given in Table X. Area 4 was not included as no clams were taken from this area.

(Insert Table X)

The geometric average of M.P.N. values of all samples of hard clams taken from Raritan Bay was almost exactly the same as the geometric average of the M.P.N. values of waters overlying these clams, i.e., 80.1 as against 80.9 coliforms per 100 ml. respectively. These values do not include the results

TABLE IX

Tabulation of clam and water coliform densities of samples taken from Areas 2 and 3.

Date 1941	Station Location	°C. Temperature	**M.P.N. Water	** M.P.N. Hard Clams
		Area 2		
Apr. 15	35, 46, 44	10	900	230
" 15	33, 48	10	2500	230
" 30	35, 46, 44	11	900	490
" 30	33, 48, 47	11	2000	220
May 22	68, 70	16.5	500	120
June 17	81	19	300	45
" 17	68	19	213	68
" 17	84	19	100	20
" 10	70	18	945	110
" 10	72	18	848	78
Average		15.1	* 633	* 114
		Area 3		
Apr. 16	30, 31	11.8	200	230
" 16	27, 29	11.8	35	45
May 1	30, 31	14	200	310
" 1	27, 29	14	35	230
" 15	30, 31	15	200	3500
" 15	27, 29	15	35	1300
" 19	51	14	50	20
" 26	30, 31	15.8	200	20
" 26	27	15.8	40	20
June 3	52	17.5	30	† ≤ 23
" 16	27	19	40	20
" 16	52	19	25	20
Average		15.2	* 63.3	* 85.9

(*) Geometric

(**) Most probable number per 100 ml.

(†) Assumed as 15.

TABLE X.

Average** coliform M.P.N. results from water and hard clam samples from Raritan Bay

Area	1	2	3	5	6	7	8	Entire Bay
Water Temp. °C.	16.9	15.1	15.2	10.8	16.1	14.8	15.4	15.7
*M.P.N. Water	87.	630.	63.	1500.	110.	55.8	43.	80.9
*M.P.N. Clams	120.	110.	86.	2800.	56.	66.4	38.1	80.1
Number of Clam Samples	41	10	12	1	8	29	24	125

(*) Geometric averages of most probable number per 100 ml.

(**) A complete table of M.P.N. values for hard clam samples and overlying waters, with locations is given in Table 3, Appendix I.

from any samples taken at temperatures during which clams and other shellfish hibernate and they are, therefore, representative of feeding temperatures except in the range above 20°C. Loosanoff(11) has shown that hard clams rest below about 4°C., are open an increasing percentage of the time up to 10°C., and vary but slightly in the percentage of time open above 10°C.

It seems, therefore, that coliform densities in macerated hard clams on the average, equal the coliform content of the overlying water, or possibly even exceed this value by as much as 1.5 times at temperatures above 10°C. These results, in general check those of Fisher and Acker(12) for oysters at Naragansett Bay, where the distribution of oyster and water scores at temperatures above 5°C. was shown to be quite similar. At temperatures below 5°C. the oyster scores were much lower than water scores, with a fair percentage showing zero scores ($\leq$ 23 per 100 ml.). Bidwell(13) in his excellent analysis of the extensive data collected by the New York State Conservation Department laboratory at Freeport, N. Y., has shown that oysters and hard clams tend to have similar M.P.N.'s (Great South Bay) but soft clams from the same waters tend to be much higher in coliform content than either hard clams or oysters.

The reasons for the difference between hard clam scores in area 2, and to some extent in area 6, and the remaining five areas of the bay is not known, but it is believed that the difference is statistically significant in spite of the small numbers of samples available. The water in area 2 is fairly deep, however, and is quite close to the relatively unpolluted ocean. The most obvious explanation would be, therefore, that water samples taken at a depth of 5 feet were grossly inadequate to measure average pollution in this area, especially that reaching the level of shellfish on the bed of the bay.

III. SHELLFISH STANDARDS.

The preceding chapters have been largely devoted to the condition of the bay as determined by the bacteriological tests made during the survey and to a discussion of the sources of pollution and physical factors affecting Raritan Bay waters. The remainder of the report will cover the second and more difficult phase of the investigation, i.e., the public health implications of these findings. Inasmuch as the resources available for research on the problem were quite limited, this latter phase must necessarily deal in opinions, substantiated largely by information available in the literature, and personal experiences rather than facts. Certain aspects of the general problem of standards together with a rather interesting theory of infectious dosages of E. typhosa, however, seem worthy of presentation in this report even though there is insufficient supporting evidence to warrant definite conclusions. Such an approach has the additional justification of stimulating research leading to the development of more reliable basic data.

It is, of course, highly desirable that bacteriological standards be promulgated for both shellfish and producing waters and that these standards express, with a suitable factor of safety, the upper limit of allowable pollution beyond which enteric diseases may occur following the consumption of such shellfish or of shellfish taken from such waters. Basically, the most accurate approach to these standards lies in a combination of epidemiology together with the bacteriology of enteric pathogens in the shellfish, from which must be obtained a bacteriological standard for the shellfish in terms of some bacteriological test, such as the coliform test, suitable for routine usage in a large number of control laboratories. Standards for shellfish bearing waters must, of necessity, reflect the allowable bacterial content of the shellfish grown in those waters, bearing in mind that the shellfish concentrate the bacteria of the overlying water to a degree that varies with the species of shellfish, with the temperature at the time of their digging, and probably with other undetermined variables.

Bacteriological standards for shellfish and shellfish bearing waters are concerned only with relatively dilute pollution and to a certain extent, that of relatively ancient origin, where the time required for the pollution to reach the beds is a minimum of several days or more, or where the processes of natural purification have greatly decreased the original bacterial content of the polluting wastes. The literature of epidemics of shellfish-borne enteric diseases is largely a repetition of epidemics caused by recent and heavy pollution and an excellent example of this is provided by the continuous record of typhoid fever cases due to eating clams from Jamaica Bay, N.Y., as discussed in the article "Canarsie Clams and Typhoid Fever".(14)

It is possible to infect an otherwise satisfactory shellfish bed, intermittently, as by casual fecal discharge or with practically a pure culture of E.typhosa from a urinary carrier, either of which conditions would nullify the coliform test as an indicator of such pollution. It is, therefore, obvious that any pollution which is subject to wide fluctuations in its content of pathogens, being quite dangerous, must be excluded on grounds other than its exceeding the allowable coliform limit. This reasoning applies to non-disinfected effluents from small sewage treatment plants. A similar situation would arise even with relatively dilute pollution during the occurrence of an epidemic or unusual prevalence of enteric diseases. An excellent example of this is reported in the Bacteriological and Chemical section of the annual reports of the London Metropolitan Water Board for the years 1931 to 1938.(15 to 22) In these reports the high concentration of paratyphoid bacteria in the sewage of Epping, following an outbreak, was determined routinely for several years by the London Metropolitan Water Board Laboratories, and to protect the London supply, the sewage of Epping has been continuously chlorinated. The abnormally large numbers of pathogens discharged during such an epidemic would falsify the normal interpretation of the coliform test, or any test not specific for that particular pathogen, because such non-specific tests are essentially, consciously or unconsciously, an expression of the ratio of $\frac{\text{pathogens}}{\text{organisms tested for.}}$ Any sudden or unusually heavy concentrations of pathogens in sewage could only be cared for by using a very large factor of safety. It is felt, therefore, that unusual prevalence, or the occurrence of an epidemic of enteric diseases in a town should result in the temporary closing of any shellfish beds polluted by even dilute wastes from that town. This would apply even though the shellfish and overlying waters meet accepted bacteriological standards which are not specific for the particular organism involved, unless the sewage, or sewage effluent, be subjected satisfactorily to some disinfecting process, such as chlorination.

The following portion of the report deals largely with the condition of relatively dilute pollution and attempts to evaluate the public health significance of such pollution by the expression of the ratio of $\frac{\text{E. typhosa}}{\text{coliforms}}$ and the factors affecting this ratio.

IV. ISOLATION OF ENTERIC PATHOGENS

Brief Review of Literature

The isolation of *Eberthella typhosa* and other enteric pathogens from water and sewage, known vectors for the transmission of many intestinal diseases, has long been of interest to those responsible for the bacteriological control of water supplies. The introduction in 1927 of Wilson and Blair's bismuth sulfite agar has resulted in a large amount of work being done during the past 10 or 12 years by a number of investigators. These workers have been successful in isolating *E.typhosa* from sewage and polluted waters using Wilson and Blair's media or various modifications of it. While it hardly seems necessary to review the literature extensively in this report, several of these workers, or groups of workers, have made numerous isolations of *E.typhosa* and other enteric pathogens. The work of the London Metropolitan Water Board Laboratories is perhaps the most complete and carefully controlled. Starting under the late Sir Alexander Houston, the reports of 1927 to 1938 (15 to 26) each carries some reference to isolations of enteric pathogens and the total amount of this work is very considerable. It includes isolations or attempted isolations from sewage, sewage treatment plant effluents and raw Thames River water. A number of the experiments were controlled by adding a known concentration of *E.typhosa* to half of the sample and increasing the estimated concentration of typhosa present by the ratio of

$$\frac{\text{E.typhosa added to control}}{\text{E.typhosa recovered from control}}.$$

Such results also have value

when isolations are not accomplished from the sample inasmuch as this justifies the assumption that *E. typhosa* was absent from a fraction of the original sample equal to the ratio $\frac{\text{E. typhosa recovered}}{\text{E. typhosa added}}$ in the control. During the years 1931-1938, the London Metropolitan Water Board Laboratories also examined samples of raw sewage and effluent from the Epping sewage treatment works for *Salmonella schottmuelleri* (*B. paratyphosus B.*). This organism was found to be present in large numbers following an outbreak of 260 cases of paratyphoid at Epping during 1931, a smaller outbreak of 22 cases in 1933 and two cases in 1935. This work, together with other studies of a more limited scope constitutes the largest mass of data available on the isolation of enteric pathogens from water and sewage. Wilson(27)(28)(29) and Wilson and Blair(30) have reported numerous isolations of *E. typhosa* from polluted waters, sewage and(27) the shell liquor of cockles.

Green and Beard(31) have reported the isolation of *E. typhosa* from Palo Alto sewage in 9 of 55 1 ml. samples, Ruchhoft(32) has reported isolations in two 0.1 ml. samples of Chicago activated sludge, while Heukelekian and Schulhoff(33) reported failure to isolate *E. typhosa* from the sewages of 15 municipalities in 0.1 ml. amounts. Stewart and Ghosal(34) reported isolation of *E. typhosa* from the River Hooghly in India. Hajna(35) has reported isolations of *E. typhosa* from six of 22 samples of crude sewage, none of 9 samples of effluent, three of 7 samples of raw sludge and none of 3 samples of digested sludge from Baltimore and vicinity. From this series of samples twenty-two strains of *E. typhosa* were confirmed by Hajna. Two *E. typhosa* were isolated by Hajna from one ml. of raw sewage containing 11 billion* _Esch. coli_ per ml.

Mom and Schaeffer(36) reported an extensive series of isolations from sewage, sludge and river water at Bandoeng, Netherland Indies, where the morbidity rates for typhoid fever are around 30 cases per thousand per year. Both Wilson(27) and Mom and Schaeffer(36) stress the relationship between the typhoid morbidity rate and the concentration of _E. typhosa_ found in the sewage of a community. Accordingly, available data have been plotted (Figure 14) in order to give some idea of the relationship

(Insert Figure 14)

between reported isolations and the normal prevalence of typhoid fever in the community. The concentration of _E. typhosa_ is expressed as _E. typhosa_ per million coliforms, inasmuch as this gives an increasing value for increasing prevalence and is convenient to remember, being about 1-4 times the concentration per ml. in raw sewage.

The positions of the lines on Figure 14 are, of course, quite crude as the data available are insufficient to determine the relationship with any degree of accuracy. The nature of the curve between .2 and 30 cases per 1000 population per year is entirely unknown and the curves are plotted as linear on logarithmic paper without other than convenience for justification. There are also many factors such as individual technique of the investigators, variations in the composition of the Wilson and Blair

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(*) The 11 billion coli per ml. of sewage is quite high and may be a misprint in the original article.

agar and the methods of determination and interpretation of the coli-aerogenes group organisms. All of these factors influence the results as plotted and it has not been possible to take them into account. The upper line is the suggested ratio, as indicated by the data available, for the absolute numbers of E. typhosa in the absence of epidemic conditions, while the two lower lines indicate the ratios which might be expected, uncorrected for recovery losses, in polluted river waters and sewage. The methods used in all cases were direct plating on Wilson and Blair's agar (or some slight modification thereof) except for raw Thames River water where the bacteria were concentrated by precipitation with alum. It must be borne in mind that the ratios given in Figure 14 are the approximate minimum ratios to be expected in general in sewage, and waters polluted by sewage, from large or fairly large populations. These ratios would be increased by carelessness in disposal of infected excreta or the presence of epidemic conditions. In the absence of both cases of typhoid fever and typhoid carriers there would, of course, be no E. typhosa in the sewage, a condition which may occur in some small towns. Similarly much greater fluctuations might be expected in the sewage from smaller towns due to the large numbers of E. typhosa which a single carrier can excrete and the lack of a balancing effect due to large populations.

Isolation of Pathogens on Raritan Bay Survey.

As part of the study of waters of Raritan Bay, the Typhoid Fever Laboratory of the Division of Laboratories of the City of New York undertook the isolation of enteric pathogens from samples of the waters entering lower New York Bay through the Narrows, Raritan River, Arthur Kill and Rockaway Inlet, and also from several samples of New York City sewage. The samples used were composites of the routine samples collected for determination of the coliform content of the waters of these various inlets at two hour intervals throughout the tidal cycle. The methods used in the isolations were those used routinely by the New York City Typhoid Fever Laboratory for isolating E. typhosa in diagnostic work and from the stools of suspected typhoid carriers. A modification(37) of Wilson and Blair's bismuth sulfite agar was used together with tetrathionate enrichment broth. Tetrathionate tubes showing growth were streaked on bismuth sulfite plates and all fishings from these plates were transferred to triple sugar slants with confirmation by slide agglutination as described by Oldenbusch.(37)

The results of these isolations from the polluted waters entering Raritan Bay are summarized in Table XI.

(Insert Table XI)

The significance of the results obtained in the examination of polluted waters entering Raritan Bay is speculative but the results are believed to be of value insofar as the negative results of the bismuth sulfite plates are concerned and with the three positive isolations of Salmonella in tetrathionate broth. The latter are not necessarily considered to have quantitative significance due to the lack of any data which would indicate the percentage of single cells of the various members of the Salmonella group which would develop in tetrathionate

TABLE XI

ISOLATIONS OF PATHOGENS FROM POLLUTED WATERS ENTERING RARITAN BAY.

Date 1941	Source	Bismuth Sulfite		Tetrathionate		Coliforms per 100 ml	Total Colif. Bismuth Sulfite †† Agar	††Coliforms in Tetrathionate and Bismuth Sulfite Plantings
		Quan.* Planted Ml.	Result	Quan. † Planted Ml.	Result			
May 19	Rockaway Inlet	100	Neg.	50	Neg.	2,300	2,300	3,400
" 20	" " "	100	Neg.	100	Neg.	1,100	1,100	2,200
" 21	Arthur Kill	100	Neg.	100	2-10ml. tubes Positive Sal. panama	233	233	500
May 21	Raritan River	100	Neg.	100	Neg.	148	148	300
" 27	Narrows	100	Neg.	100	Neg.	8,590	8,590	17,200
" 27	Narrows	100	Neg.	100	Neg.	9,620	9,620	19,200
June 3	Arthur Kill	105	Neg.	2,000**	Neg.	202	210	4,200
" 3	Raritan River	100	Neg.	2,000**	Neg.	442	440	9,300
" 9	Rockaway Inlet	50	Neg.	1,600**	1-200ml. bottle positive Salmonella kaufman, Group E	3,770	1,880	62,200
June 10	Rockaway Inlet	50	Neg.	1,600**	Neg.	2,550	1,280	42,100
" 16	Narrows	90	Neg.	3,000**	Neg.	15,000	13,500	464,000
" 17	Narrows	60	Neg.	2,000**	Neg.	2,120	1,270	44,000
" 24	Arthur Kill	65	Neg.	2,000**	Neg.	236	150	4,900
" 24	Raritan River	60	Neg.	2,000	Neg.	364	220	7,500
" 30	Narrows	90	Neg.	2,400**	Neg.	16,700	15,000	416,000
July 1	Narrows	75	Neg.	2,400**	Neg.	8,180	6,140	202,000
	Sum	1,345		21,550			62,081	1,299,000

* Planted 5 ml./plate   ** Planted in 200 ml. quantities with double strength tetrathionate broth.

† Planted 10 ml./tube unless otherwise noted.

†† Coliforms in these columns represent the total estimated coliforms in the water planted on the specified media.

broth, the problems presented by overgrowth and other unfavorable conditions. These problems are illustrated by the results of mass inoculations of sewage, referred to later.

Regarding the negative results for E.typhosa among colonies picked from bismuth sulfite plates, it may be fairly assumed that of 1345 ml. of these waters containing an estimated 62,100 coliforms; using the recovery ratios of approximately 1/4 obtained by Houston(24)(25) that the E.typhosa per million coliforms were less than 60. Even with the recovery ratios of 100 per cent, the examination of larger quantities would probably be required for the isolation of a single E.typhosa from the waters. The absence of isolations of E.typhosa from tetrathionate broth cannot be considered as having much significance in view of the failure to get growth from large volumes of sewage. Considering all inlet water samples in Table XI, two Salmonella panama and one Salmonella kauffmann, Group E, were isolated from waters containing 1.3 million coliforms, with no allowance for recovery ratios.

Four samples of raw sewage, one 24 hour composite ending at 8:30 a.m. July 24, 1941, and one catch sample taken at that hour from Coney Island and Ward's Island sewage treatment plants, respectively, were examined for enteric pathogens by plating in serial dilution on bismuth sulfite agar and inoculation into tetrathionate broth in serial dilutions. The quantities planted for each sample were 1 - 10 ml., 2 - 1 ml., 2 - .1 ml., and 2 - .01 ml. on bismuth sulfite and 6 - 100 ml., 3 - 10 ml., 2 - 1 ml., 2 - .1 ml. and 2 - .01 ml. in tetrathionate, except

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that the two Coney Island samples had six additional 100 ml. portions each planted in tetrathionate. Positive isolations from these plantings were as follows:

Coney Island catch sample:

1 - 100 ml. tetrathionate, positive *Salmonella chester*
1 - 100 ml. " " positive *Salmonella anatum*

Ward's Island composite:

2 - 10 ml. tetrathionate, positive *Salmonella panama*
1 - 100 ml. " " positive " "

Ward's Island catch samples:

1 - 10 ml. tetrathionate, positive *Salmonella newport*
1 - 100 ml " " positive *Salmonella bareilly*

In general, the bismuth sulfite plates were negative in the highest dilution while lower dilution plates were badly overgrown. The tetrathionate results present interesting evidence of the value of this medium for isolation of Salmonellas in the presence of a very mixed, large bacterial population. They also, however, emphasize the difficulties of quantitative work under those conditions. It is unfortunate that, due to the limited time available, the experience gained could not be utilized in further studies.

It is interesting to note that a variety of pathogens have been isolated by some of the previously mentioned workers in examinations of water and sewage. *Salmonella schottmuelleri* (*B. paratyphosus B.*) is perhaps the most frequently mentioned pathogen other than *E. typhosa*. In addition to routine examination and isolation from the sewage and effluent of Epping, the London Metropolitan Water Board Laboratories have reported: One isolation(17) from 24 samples of six sewages, mean $\frac{\text{S. schottmuelleri}}{\text{million coliforms}} = \frac{20}{2.67} = 7.5$; three isolations(16) from 1,825 ml. of 11 different sewages. The 1931 Report of the Chief Medical Officer, British Ministry of Health(38) mentions the isolation of *S. schottmuelleri* in 2 ml. amounts from the effluent at Wroxall and in 100 ml. amounts from the River Var 3-1/2 miles below the point of discharge of Wroxall effluent. Gray(39) and Begbie and Gibson(40) have reported isolation of *S. schottmuelleri* from Edinburgh sewage.

Isolations of *Salmonella typhimurium* (*B. aertrycke*) have been reported by the Metropolitan Water Board(16)(19) and in the 1931 Report of the Chief Medical Officer, British Ministry of Health(38), who also reported the isolation of *Salmonella newport* (*B. newport*) from Ipswich sewage and *Salmonella enteritidis* (*B. enteritidis, Gaertner*) from Daventry sewage.

Most of the isolations reported for organisms other than *E. typhosa* and *S. schottmuelleri* (*B. paratyphosus B.*) including those reported in this study, were made incidental to the search for *E. typhosa*, and in view of the general lack of knowledge of percentages of recovery, little significance can be attached to the quantitative aspects of these reported isolations other than *E. typhosa* and to some extent *S. schottmuelleri*.

The *E. typhosa* Coliform Ratio

The expression of *E. typhosa* concentrations in both sewage and polluted waters as a ratio, such as the E. typhosa per million coliforms as used in Figure 14, implies the existence of equal logarithmic rates of decrease with time of these organisms under the same environment. There is much to support such an assumption, however, in that many of the factors which combine to form "natural purification rates" such as ingestion by protozoa and sedimentation would not be expected to differentiate between groups of organisms which do not differ too greatly in essential characteristics such as optimum growth requirements, size and motility. Perhaps the best evidence of equal rates of decrease yet collected is furnished by the work of the London Metropolitan Water Board in isolations of Salmonella schottmuelleri (B. paratyphosus B.) from the sewage and effluent at Epping over a period of years. These results, usually 17 samples each of sewage and effluent per year, have been summarized in Table XII, which presents the median ratio of

(Insert Table XII)

$\frac{\text{Esch. coli}}{\text{S. schottmuelleri}}$ found in Epping sewage and effluent. It will be noted that the mean of the median ratios is 1518 for raw sewage as against 1105 for final effluent. This greater ratio in raw sewage is about what one would expect if S. schottmuelleri are more difficult to isolate from raw sewage than final effluent. It will be remembered that Houston was able to recover 1/3.1 (25) and 1/4.8 (24) of E. typhosa added to river water, but only 1/10.9 (26) of the same organism added to raw London (Barking) sewage.

Considering the fact that each pair of these samples has undergone identical purification varying between 85.5 and

TABLE XII

RATIOS OF ESCH.COLI/S.SCHOTTMUELLERI IN RAW SEWAGE AND EFFLUENT FROM EPPING, ENGLAND.

Year	Reference	Median Coli/S.schottmuelleri		Per cent Coli Reduction	Method of Sewage Treatment
		Sewage	Effluent		
1931	15	278	* 190	96.8	Land treatment
1932	16	156	> 300 †	85.5	" "
1933	17	992	250	94.1	" "
1934	18	714	>300 †	95.5	" "
1935	19	5,000	1,500	98.7	Trickling filters
1936	20	1,000	3,000	98.7	" "
1937	21	2,000	>300 †	99.2	" "
1938	22	2,000	3,000	99.3	" "
Mean		1,518	1,105	97.0	

* Omitting effluent samples prior to May 11 to secure comparable data.

† Salmonella schottmuelleri not isolated from quantities of effluent containing median numbers of coliforms. Median would be slightly higher if these results were omitted.

99.3 per cent, such purification being essentially an accelerated natural purification, the net result constitutes the strongest sort of evidence justifying the use of $\frac{\text{enteric pathogen}}{\text{coliform}}$ ratios for natural purification processes probably up to 99.9 per cent reductions from raw or diluted raw sewage. Beyond that percent purification, it seems likely that additional evidence will be required as to relative reductions of pathogens and the coliform group as most curves for coliforms tend to slacken from a straight logarithmic rate of decrease, probably somewhat sooner than the rates of decrease for the more limited number of strains of enteric pathogens.

Additional, though somewhat indirect, supporting evidence for parallel reductions of pathogens and coliforms is presented by Ruchhoft(61) and his co-workers in their studies of decreases of coli-aerogenes group organisms in the Illinois River. The authors conclude "These results indicate that during self-purification of polluted water there is comparatively little change in the ratio of *Bact. coli* to *Bact. aerogenes*".

Rates of Decrease of E.typhosa and Coliforms under Conditions of Natural Purification.

A large number of investigators have studied the rates of decrease of *E.typhosa* under a variety of conditions. These studies are rarely directly comparable and quite frequently were not strictly quantitative. Many of the earlier studies were based on an absence of *E.typhosa* from a qualitative test only for this organism, and the results are therefore of limited value in quantitative studies. Much of the work has been carried on under conditions which were quite surely anaerobic and varied widely from normal natural purification in streams and quiescent bodies of water.

In Figures 15, 16 and 17 are shown data on rates of

(Insert Figures 15, 16 and 17)

decrease of E. typhosa published by various investigators, compared to values for the rates of decrease of coliforms and 37° agar count organisms as found on the Scioto River.(41) These are divided into three temperature ranges, 9.9°C. and below (Figure 15), 10-19.9°C. (Figure 16) and 20°C. and above (Figure 17), probably averaging for natural waters about 5°C., 15°C. and slightly under 25°C., respectively. Very little data are available for Figure 15 but Heukelekian and Schulhoff(33) presented figures for Raritan River water at 2.0°C. which were only slightly lower than comparable rates of coliform decrease on the Scioto River.(41) If the usual form of monomolecular curve, $y = b10^{-Kt}$ is chosen as representing the logarithmic rate of decrease, where y = the concentration of bacteria after time, t, in days, b = the initial concentration and K a constant dependent largely upon temperature, then the value of K assumed for a temperature of 5°C. for both coliforms and E. typhosa as indicated by the data in Figure 15 is roughly 0.5.

In Figure 16 the available evidence for determination of a K value at 15°C. is rather scattered. The data of Green and Beard(31) based on stored sewage and sewage plus sludge at 14° - 20°C. and 15° - 21°C., respectively, have a K value of about .8 - 1 during an early logarithmic rate of decline, but this decreases to about .5 at later stages. Houston's(15) figures for S.schottmuelleri in sewage effluent at 10°C. show roughly a K value of .3 while the figures of Ruchhoft(32) show K values of .1 for activated sludge stored at 10° - 15°C. Ruchhoft's figures also show approximately parallel rates of decline for coliforms and none of these figures are reasonably comparable to conditions in natural waters, being conducted under anaerobic conditions. A K value of 1. is, therefore, assumed for the temperature of 15°C. largely on the basis of Scioto River observations for coliforms, supported by the parallel rates of decrease of coliforms and E.typhosa under identical conditions as shown by Ruchhoft.

In Figure 17, Heukelekian and Schulhoff(33) show K values of about 3.0 for Raritan River water at 22°C., Wilson(29) a K value of about 0.5 for well water at 22°C., Mom and Schaeffer(36) values of 0.5 for digesting sludge decreasing somewhat after about 99.5 per cent drop in E.typhosa. Ruchhoft(32) gives rates of decrease of slightly under 1.0 for canal water at 20° - 22°C. and slightly over 0.5 for stored activated sludge at 20° - 22°C. A rough K value of 2.0 is assumed as a rate of decrease at 25°C. for both coliforms and E.typhosa, roughly averaging the available data for typhosa and coliforms. The relationship between the rates of decrease and temperature is shown, plotted on semi-log paper, in Figure 18.

(Insert Figure 18)

If the rates of decrease of coliforms and E.typhosa in natural waters are equal for decreases up to 99.9 per cent then a constant $\frac{\text{typhosa}}{\text{coliform}}$ ratio could be assumed for 1.5 days at 25°C., 3 days at 15°C., and 6 days at 5°C., starting with fresh pollution such as sewage or dilute sewage and using the values of K derived from the data presented in Figures 15, 16 and 17.

Discussion

The assumption of $\frac{\text{typhosa}}{\text{coliform}}$ ratios is a logical and rational approach to a more exact and quantitative use of the estimation of coliforms as an indicator of sanitary conditions. This ratio is supported by considerable evidence as presented in the preceding pages of this report and should give additional, if not absolute, legal status to the coliform test which has recently received an adverse decision in the Courts of Illinois.(42) This study presents little more than a start upon the work needed before such a ratio could have much practical value, inasmuch as the limits of its usefulness should be clearly defined. Some of the factors which should be investigated are: (1) variations to be expected in the ratio in different sewages, (2) the changes, if any, encountered at low coliform concentrations due to high rates of natural or chemical (chlorination particularly) purification, (3) the significance of coliforms from sources other than sewage, and (4) whether, in the presence of coliforms largely from sources other than sewage, isolation of enteric pathogens can be made.

It should be remembered that while it is theoretically possible to have a pure, or practically pure, culture of E. typhosa under natural conditions (urination by a carrier into pure water) such an occurrence in sewage, particularly from a large population, is quite impossible and in general the occurrence of high $\frac{\text{typhosa}}{\text{coliform}}$ ratios in sewage would presumably be made known by the presence in the contributing population of the epidemic which preceded these high ratios.

It is believed that the actual determination of the $\frac{\text{typhosa}}{\text{coliform}}$ ratio and its variation would be worthwhile in many instances, particularly where a polluted water is used as a source of supply.

V. WATER AND SHELLFISH BORNE TYPHOID FEVER.

It is beyond the scope of this report to present an extended discussion of water and shellfish borne epidemics of typhoid fever. It is desired to separate epidemics of typhoid fever, more or less arbitrarily into two groups according to the presumed intensity of infection and to discuss at length only those of presumably light infectious dosages.

In the category of heavy or uncertain infectious dosages would be included most carrier-borne typhoid, most milk-borne typhoid and water-borne typhoid with quite heavy attack rates for the population exposed or where the epidemic was traced rather definitely to more or less direct carrier or patient discharge. The majority of recorded epidemics in Great Britain would fall, it is believed, into this last category. An example of the latter is the Denby Dale outbreak discussed in the 1932 Annual Report of the Chief Medical Officer, British Ministry of Health. This epidemic involved 56 primary cases in a population of 3402 and was traced rather directly to contamination of the water supply reservoir by 12 days excreta from a typhoid fever patient. An interesting small outbreak of typhoid fever, with presumably heavy infectious dosages, was reported by Morales and Mandry(43) where 9 of 18 persons regularly using water from a cistern, directly and heavily contaminated by carrier discharges, contracted typhoid fever, Of the nine regular users who escaped,

one had had the disease previously and two others had had typhoid immunizations. Wilson(29) reports an outbreak at

Lisnaskea Infirmary where 23 of 70 patients in the hospital contracted typhoid fever following the admission of a typhoid case to the hospital. This outbreak was apparently water-borne, the wells being subject to pollution by sewage of the institution. Isolations from three samples of well water (following the outbreak) gave estimated densities of 100, 87, and 30 typhoid bacteria per 100 ml.

Although the dividing line between the two chosen classifications of epidemics is not sharp, and no definite distinction can be made in many instances, the second group of outbreaks of typhoid fever might be termed as due to diffuse infection. These epidemics would be characterized by quite low attack rates for typhoid fever, frequently preceded by widespread occurrence of gastro-intestinal disturbances. Such outbreaks have been so frequently recorded in the United States that one might expect such an outbreak in event of the failure of chlorination when treating a highly polluted raw water. The general pattern of frequently occurring widespread gastroenteritis followed by a few cases of typhoid fever, is quite disturbing and the occurrence of such an outbreak in Great Britain at Kidderminster led Sir George Newman(44) to state, "Nevertheless B. typhosus is still with us with all its potentialities for evil when conditions are favorable and the vehicle for its transference to the human being is forthcoming and set forth below is a brief account of a water-borne illness from which it is estimated more than 4,000 people in one town (of 29,000 population) suffered. There is strong circumstantial evidence, amounting to proof, that many of those imbibed the typhoid organism but only a very few contracted enteric fever". (9 cases of typhoid fever).

Infectious Dose for Typhoid Fever.

Bearing in mind the frequency of occurrence of this pattern of epidemic, widespread gastro-enteritis followed by a few cases of typhoid fever, and the usual concentrations of E. typhosa encountered in sewages and polluted waters as given in Figure 14, one is forced to the conclusion that in general it seems unlikely that a single individual would, under such conditions, imbibe more than a single typhoid bacterium or at most a very few. The theory is advanced, therefore, that a single typhoid bacterium is infective to a small percentage of the general population. An example of the nature of concentrations involved would, at this point, be quite interesting. Let it be assumed that a water plant is treating water with a typhosa/coliform ratio of 10 per million, corresponding roughly to that found by Houston in the Thames and in London sewage. If filtered, but unchlorinated, water were distributed containing 500 coliforms per 100 ml., corresponding to positives for coliforms, in five of the 10 ml., five of the 1 ml., and two of five 0.1 ml. portions, then the chance of an individual obtaining one E. typhosa in a daily portion of one liter of water would be about 1/20. Two E. typhosa from one liter of water would presumably be imbibed by 1 in 400 persons and three by 1 in 8000 according to the laws of probability and assuming uniform distribution of bacteria. Therewould, of course, be little reason to expect that three typhosa would be much more infective than a single one. Yet such an occurrence, namely, the passage of 500 coliforms per 100 ml. of drinking water, in the absence of any knowledge concerning the concentration of E.typhosa, would, it is believed, give rise to outbreaks of gastro-enteritis followed by a few cases of typhoid fever in the majority of instances.

A question immediately arising is: what percentage of the general population would, on the average, develop a case of typhoid fever from the ingestion of a single E.typhosa? The definite answer to this question awaits a quantitatively controlled series of isolations of E.typhosa from samples of water supplies taken from the distribution system shortly after polluted water is by-passed or even during the early stages of the gastro-enteritis phase of the outbreak. The methods used by Houston(24)(25) should be adequate if applied to sufficiently large quantities of water. This has probably never been accomplished in diffuse infections although there are records of isolations following explosive outbreaks involving a high percentage of exposed individuals such as the previously mentioned work by Wilson(29) and the isolations reported in a review of a paper by Klassen.(45)

In an attempt to obtain an approximate estimate of the number of persons in a population group which might be expected to contract typhoid fever from ingestion of a single typhoid bacterium according to the theory presented, a study was made of the data presented by Gorman and Wolman(46) in their book on water-borne typhoid fever outbreaks during the years 1920-1929.

These authors classify outbreaks of water-borne gastro-enteritis and typhoid fever into 7 main groups and 27 sub-groups according to the defect responsible for the condition causing the outbreak. Of these 27 sub-groups, eliminating such causes as defects in the distribution system, underground supplies and unknown supplies, the following classifications have been selected as those which would be expected to include largely "diffuse" infections:

A. Surface Water Supplies.

1. Contamination of brook or stream by pollution on watershed.
2. Use of polluted river water - untreated.
3. Use of polluted lake water -- untreated.
4. Contamination of spring, well or infiltration gallery by pollution on watershed.
5. Contamination of spring, well or infiltration gallery by flood waters.

B. Reservoirs or Cistern Storage.

1. Seepage from sewer or surface into cracked cistern or reservoir.

C. Water Purification.

1. Inadequate control of filtration and allied treatment.
2. Inadequate chlorination - when only treatment.
3. Interruption of chlorination - when only treatment.

A total of 86 epidemics in these classifications were grouped and arranged in the order of increasing percentages of population contracting typhoid fever. A plot of this curve is shown in Figure 19. It will be noted that the distribution of

(Insert Figure 19)

the outbreaks on the basis of the percentage of persons contracting the disease is such that for some distance the rise is approximately linear, departing from linearity noticeably when the attack rate is between one and two per cent. If reasonably uniform distributions of concentrations of E.typhosa were present in these 86 outbreaks, one would expect a more or less sharp rise in the percentage of persons contracting the disease when exposed to more than a single bacterium. The percentage of persons contracting the disease, following ingestion of a single bacterium, based on the deviation from linearity in Figure 19 would seem, therefore, to be in the neighborhood of one to two per cent rather than, say, eight per cent or more, or even some smaller figure such as 0.5 per cent or less. This sort of reasoning is, of course, extremely crude, but is valuable as a first approximation for estimating the expected cases in specific outbreaks.

Attempts have been made, therefore, to determine whether it is possible to account for certain epidemics by the presence of E.typhosa in typhosa/coliform ratios which have been reported in sewage, using 1.5 per cent as the attack rate for typhoid fever following ingestion of a single bacterium. In only a few instances has it been possible to get sufficient data on "diffuse" infections to make even a rough estimate of the concentration of E.typhosa in the water supply responsible for the epidemic.

Santa Ana, California, 1924. This outbreak was reported by Halliday and Beck(47) and as a news item in the Engineering News-Record.(48) The outbreak involved some 300 cases of typhoid fever and 10,000 cases of gastro-enteritis in two waves. On December 28, 1923, due to a surcharged sewer system following a storm, there was pumped into one of the city reservoirs an estimated 49,000 gallons of 10 per cent raw sewage (7 hours at 163,000 gallons per day), which was later pumped into the city mains. Dilution was such that no complaints were received of tastes and odors. Using an estimated coliform content of 200,000 coliforms per ml. for a rather dilute sewage and a typhosa/coliform ratio of 20 per million for the sewage corresponding to an annual morbidity rate of 0.8 per 1000 population (Figure 14), about 400 *E.typhosa* would be expected in each liter of 10 per cent sewage or 74,000,000 typhosa in the 49,000 gallons. Of these about 0.1 per cent would presumedly be ingested, or 74,000 *E.typhosa.* If these were uniformly mixed and passed out among the 30,000 population, the average number would be 2.5 per person, making no allowance for a probably rather low rate of natural decrease of *E.typhosa* in the reservoir and distribution system. Inasmuch as about one per cent of the population contracted typhoid fever, it can be seen that the incidence of typhoid fever due to the *E.typhosa* in normal sewage is of the same magnitude as would be expected assuming that 1.5 per cent of individuals exposed to a single bacterium would contract the disease. The inaccuracies in the base data must be borne in mind, of course.

Epidemic at Ponce, Puerto Rico, (1938). This epidemic was reported by Lopez(49) and involved 198 cases of water-borne typhoid fever in a population of 64,000. Records of the water plant indicate that about three to four of each five 10 ml. portions examined were positive for coliforms during the period of July 1st to August 10th inclusive, giving an estimated density of about 10 coliforms per 100 ml. With a consumption of one liter per day, the average coliform intake during this 40 day period would be 4.000 per person. Typhoid fever cases had averaged 50 per year for the preceding two years, or about 0.8 cases per 1000 population, which from Figure 14 would indicate an expected 20 *E. typhosa* per million coliforms in the polluted raw water. Using these assumptions, there would be one typhoid bacterium to 50,000 coliform or one exposure to each 12.5 persons. If only 1.5 per cent of those exposed to a single bacterium contracted the disease, it is necessary to assume a ratio of one *E. typhosa* to 20,000 coliforms to account for the reported cases. Such an assumption would, however, be in accord with known conditions, inasmuch as a single carrier can excrete tremendous numbers of typhoid bacteria. Furthermore, the assumption of a higher minimum infectious dose than a single bacterium for typhoid fever would, in this as in many instances, require a tremendous total infection of the water supply. In the particular epidemic under discussion it should be pointed out, however, that a more intense infection of shorter duration could easily have been the cause.

Detroit, Michigan, February, 1926. This outbreak, involving 45,000 cases of gastro-enteritis and eight cases of typhoid fever was reported by Gorman and Wolman.(46) Data on the coliform content of the treated water were obtained by private communication. In this outbreak, the coliform content of the treated water at the filtration plant was listed as zero for all days of the month of February, 1926, except the 25th and the 26th, when the average M.P.N. was 3.0 and 10.0 per 100 ml., respectively. If the mean intake of city water per person is estimated at about 0.5 liter for two days (in winter) with a concentration of 6.5 coliforms per 100 ml., and the 1925 mortality rate of 2.7 deaths per 100,000 be multiplied by 10 to get an average morbidity rate of .27 cases per 1000 population, then from Figure 14 the expected concentration of *E.typhosa* in the sewage which polluted the raw water and was responsible for the epidemic would be 14 *E.typhosa* per million coliforms. From this the number of persons ingesting a single typhoid bacterium would be $\frac{32.5 \times 14}{1,000,000}$ x 1,300,000 population = 600. If 1.5 per cent of those ingesting typhoid bacteria contracted the disease 9 cases of typhoid fever would have developed, an expectancy only slightly greater and of the same order of magnitude as that which actually occurred.

Rochester, N. Y. outbreak, 1940. This outbreak has been reported by Devendorf.(50) Data concerning the coliform concentrations in the municipal water supply were received through personal communication. This outbreak, involving 30,000 cases of gastro-enteritis and five cases of typhoid fever, in a population of 260,000 was due to polluted river water pumped through a cross connection during the period from 5:00 P.M. on December 11th to about 8:00 A.M. on December 12th, 1940. Analyses on

December 13th of 72 scattered water samples showed a mean coliform concentration of 102+ per 100 ml. Prompt and energetic "boil water" notification probably limited the exposure to less than a single day, and typhoid immunizations may have had some effect. If we assume however an average intake during the period prior to "boil water" notification of 200 ml. of polluted water having, say 125 per 100 ml. coliform content, for all of the population tributary to the water supply affected it should not deviate greatly from actual conditions. Rochester had .6 deaths per 100,000 from typhoid fever in 1939, corresponding to a morbidity rate of 0.06 cases per 1000 which from Figure 14 would give an estimated seven E.typhosa per million coliforms in sewage polluted water. The exposures to a single typhoid bacterium would be $\frac{2 \times 125 \times 7 \times 260,000}{1,000,000} = 455$ exposures of which 1.5 per cent, or seven cases would be expected, or approximately the number, five cases, which developed.

In view of the general correspondence of expected and actual cases of typhoid fever based on reported concentrations of E.typhosa in sewage and a theory of single cell infections, it is interesting to speculate on the possible nature of infective dosages where high percentages of the population contract the disease during an epidemic. Very little information is available on this subject but Wilson(29) isolated E.typhosa from Lisnaskea Infirmary water in a concentration of one per ml. shortly after an epidemic involving 23 of 70 patients. In the 1931 report of the Chief Medical Officer, British Ministry of Health(38) typhoid bacteria were reported in concentrations of 40 and 60 per ml. in Havant sewage effluent. About 1.5 years prior to this 18 of 99 persons who drank from a stream receiving the effluent from this plant developed typhoid fever. It seems likely that in both instances the concentration of E. typhosa in the water ingested was less, probably considerably less, for stream water containing Havant effluent, than that reported in the water and sewage effluent at the time of the isolations, the dilution and time of flow factors being unknown at Havant. A suggested relationship between the intake of E. typhosa and percentage of cases developing is shown in Figure 20, starting at

(Insert Figure 20)

1.5 per cent for single cell ingestion and increasing at a linear rate for the per cent of the population affected against the logarithms of typhoid bacteria ingested. There is, of course, no proof that such a relationship even exists, although a massive dose would be expected in common with most experience, to produce a greater percentage of cases than a smaller dose.

The question of occasional cases of typhoid fever from water supplies which meet present accepted standards of about one coliform per 100 ml. is quite an important problem. It will be remembered, however, that the estimated limit of purification previously considered for a constant typhosa/coliform ratio was about 99.9 per cent purification from sewage or diluted sewage. Most raw waters for surface water supplies have already undergone natural purification of this order of magnitude or greater. To this must be added from data published by Streeter(51, table 5-B) annual average purification plant removal for coliforms which he found to vary from 96.6 to 99.9995 for Great Lakes waters. Thus it will be seen that in normal water plant operation a problem is presented of the fate of typhoid bacteria, relative to that of coliforms, in extremely low concentrations subjected to rather severe conditions.

While there is most assuredly no widespread typhoid fever due to water supplies which meet present standards, as proven by present low typhoid rates, there is, equally, no assurance that an occasional case of water-borne typhoid fever does not develop under such conditions.

In fact, if the theory of single bacterium infection is valid there are undoubtedly occasional cases of typhoid fever due to water supplies which meet approved standards. Such an event would probably only occur under conditions favorable to the passage of the typhoid bacterium and would probably require a high initial typhosa/coliform ratio in the raw water. Suggestions of such an occurrence are indicated by the Minneapolis typhoid fever epidemic of 1935.(52) The investigators of this outbreak could find no common source of infection other than water from the Fridley purification plant which had rarely been positive for coli-aerogenes organisms in 10 ml. portions, although during the period of its presumed infectiveness, low chlorine residuals were present and there were considerable numbers of lactose-fermenters which did not confirm for coli-aerogenes. The epidemic involved 214 cases scattered over a three months period. As part of the investigations following this outbreak, Heathman, Pierce and Kabler(53) studied the comparative resistance of various strains of E.typhosa and coli-aerogenes to chlorine and chloramine. They found a considerable variation in the resistance of different strains of E.typhosa and coli-aerogenes and that certain freshly isolated strains of E.typhosa were more resistant than those which had been grown for some time upon artificial media. It is difficult to accept their implied suggestion of chlorine resistant pathogens, in the Minneapolis outbreak, however, in view of their own findings of the variation in resistance of individual strains, of both groups of organisms to chlorine and the obviously much larger number of strains of coli-aerogenes compared to those of E.typhosa which are normally present in sewage polluted waters. The exact effect of chlorine upon the large numbers of strains of the coli-aerogenes group compared to the few strains of E.typhosa present is problematical especially after bacterial decreases had continued to the range of potable waters. It is believed, however, that on the average, this ratio $\frac{\text{E.typhosa}}{\text{coliforms}}$, would tend to be decreased in chlorinated waters.

It is interesting to note that Phelps(62) in his early experiments on the comparative resistance of aqueous emulsions of B.typhi and B.coli to calcium hypochlorite concluded that "the slight differences shown by the experiments on the two organisms may be attributed to experimental variations".

The averaged results of 12 sets of observations were:

Time	% Removal	
	B. typhi	B. coli
20 minutes	90.5	92.0
40 "	98.2	98.0
1 hour	99.45	99.53
2 "	99.60	99.70
4 "	99.92	99.96
18 "	99.99+	99.99+

Average available chlorine was 5.0 p.p.m.

Consideration in this report of water-borne outbreaks due to pathogens other than *E.typhosa* has been limited due to the lack of knowledge of the absolute infectiveness of such pathogens, the concentrations in which they occur and their rates of decrease under natural conditions.

Typhoid Fever from Shellfish

Dodgson(54) has reviewed and summarized several reports of outbreaks of typhoid fever due to shellfish and discusses extensively (pages 6-27) British experience with shellfish borne typhoid fever in coastal towns. One rather striking comment which Dodgson makes is "In this connection it is interesting to note that in the case of all the well authenticated instances of epidemics of typhoid or paratyphoid arising from the consumption of shellfish, there has always been a large number of coincident cases of diarrhea and/or other gastro-intestinal disturbance . . . in the order of 10 (gastro-enteritis) to 1 (typhoid) and in one case, about 40 to 1".

Another rather striking feature of most of the epidemics which Dodgson discusses is the usually very evident and direct pollution of the shellfish by floating in sewage polluted waters or by taking from waters rather directly polluted by sewage which leads Dodgson (page 11) to state, "In the opinion of the writer, the *crux of the whole question is the rapidity with which the typhoid or other pathogenic bacterium may be transferred from the human source of infection to the shellfish consumer*". Rosenau(55) cites a number of outbreaks due to infected oysters, mentioning one, reported by Bulstrode, where 21 cases of typhoid fever and 118 cases of gastro-enteritis developed among 267 guests who had eaten raw oysters at a banquet. This is an attack rate for typhoid fever of about eight per cent, assuming that all persons eating the oysters also ingested typhoid bacteria. In line with the previous discussion of the theory of single cell infections, and the usual rates of attack in water-borne gastro-enteritis-typhoid fever outbreaks with low attack rates for typhoid fever, the minimum possible typhoid fever attack rate at this banquet of eight per cent was much higher than usual water-borne outbreaks. However, a few epidemics with typhoid fever attack rates as high or higher were included by Gorman and Wolman.(46)

There is considerable evidence, however, that typhoid fever due to shellfish which would correspond, in order of magnitude of intensity, to water-borne attack rates of somewhat less than one per cent would not result in traceable epidemics but would, on the contrary, result in an isolated case or two which, with the coarse yardsticks of epidemiology, could not be traced to shellfish. Such cases would end up in the "source unknown" column unless, by chance, diligent search revealed a carrier of E. typhosa somewhere in the vicinity. The patient may even have been outside the boundary of his particular city within the 10-30 day period preceding onset, in which case it may be possible to shift the source beyond immediate geographical boundaries, practically getting rid of it completely with the notation "roadside spring" or "swimming". All this is not presented in the spirit of criticism of present epidemiological methods, but to emphasize the inherent coarseness of such available methods and their inapplicability to isolated cases of typhoid fever. Furthermore, the epidemiologist should, and probably generally does, recognize the inherent limitations of present epidemiological methods in dealing with and further reducing present low typhoid morbidity rates. If the theory of single cell infections is valid, it should throw new light on, and be an important tool for, such epidemiological investigations.

Consideration of Shellfish Infection.

In the previous discussion of the pollution of Raritan Bay, several factors came to light which seem quite important in the analysis of shellfish infections using the $\frac{\text{typhosa}}{\text{coliform}}$ ratios.

1. Studies of the rates of decrease of coliforms indicate that present pollution in the heaviest polluted areas of Raritan Bay is to a great extent relatively fresh pollution with, therefore, probably, unchanged $\frac{\text{typhosa}}{\text{coliform}}$ ratios from those present in the sewage.
2. Coliform densities in macerated shell clams, on the average, equalled or perhaps exceeded by 1.5 times, the coliform density of the overlying waters during

the period of active feeding, 10°C. and above.

3. From temperature-feeding relationships and general experience, backed by considerable analytical evidence, it is concluded that hard clam coliform densities are quite low during hibernation, below 4°C. Between 4° and 10°C. an intermediate value should probably be assumed, possibly .5 - .8 of the coliform density of the overlying waters.

As an example of low temperature coliform densities, of 62 samples of Raritan Bay hard clams analyzed by the New York State Conservation Department laboratories between January 4 and April 30, 1940, only seven samples showed confirmed coliforms, four samples having an estimated 20 per 100 ml., one with 38, one with 45 and one with 75 per 100 ml.

In the discussion which follows, therefore, the coliform content of hibernating clams will be excluded and values of .6 and 1.3 times the coliform density of the overlying waters will be assumed for 4° - 9.9°C. and 10°C. and above, temperature ranges, respectively.

From Figure 6 which gives the approximate temperature cycle of Raritan Bay, it is evident that hard clams taken from the bay during the months of December, January, February and March should have a negligible coliform content, those taken during November and April, 0.6 of the coliform density of the overlying waters and during May, June, July, August, September and October, about 1.3 times the coliform content of the overlying waters.

The seasonal distribution of receipts of hard clams at the New York City Salt Water Market for 1939 is given in the U.S. Bureau of Fisheries Bulletin(56), as follows:

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Tot.
Million Lbs.	2.00	2.09	2.10	1.85	2.1	2.18	1.99	2.06	1.97	1.92	1.71	1.62	23.59

or during the periods previously mentioned the following percentages of total annual production were marketed here:

Months	Million Lbs.	Percent
Dec., Jan., Feb., Mar.	7.81	33
Nov., April	3.56	15
May, June, July, Aug., Sept., Oct.	12.22	52

A composite picture of 52 per cent plus one-half of 15 per cent would indicate that 60 per cent of the hard clams reaching the market would contain 1.3 times the mean coliform density of the waters from which they were taken, at the time of digging. The distribution of oyster harvesting is quite different from that of hard clams, inasmuch as oysters are not taken in appreciable quantities during the months of May, June, July and August.

To give some idea of the magnitude of the quantities involved, the New York State Conservation Department estimates that about 150,000 bushels of hard clams were dug from the New York State open areas of Raritan Bay in 1940 and data from the

Bureau of Fisheries Bulletin(56) for Monmouth and Middlesex Counties, New Jersey, indicate that New Jersey production of hard clams from the bay amounts to perhaps 25,000 bushels, or a total from the bay of 175,000 bushels. Omitting area 4 in New Jersey, from which clams are not dug, a weighted mean coliform density of bay waters has been computed, based on planimetered areas between lines of equal coliform content within areas of the bay open for the taking of shellfish. The weighted mean coliform densities of bay waters in New Jersey and New York open for the taking of hard clams, and omitting area 4, are given in Table XIII.

(Insert Table XIII)

Multiplying the weighted mean densities of 167 and 56 from Table XIII by 1.3 gives a figure for the coliform density of the clams dug from the bay. To this should be applied a factor of 60 per cent to correct for the negligible low-temperature coliform densities in the clams. The estimated average coliform densities in clams dug from the open areas of New Jersey and New York are, respectively, 130 and 44 coliforms per 100 ml. of emulsified hard clam meats. If these figures are applied to the estimated shellfish production of 150,000 bushels for New York and 25,000 bushels for New Jersey, using uniform factors of 9 pounds of clam meats per bushel of shell clams and 4.5 hundreds of ml. per pound of clam meats, then the total coliforms in the annual production of hard clams from Raritan Bay would be about 400 million. Using an average figure of 250 cases of typhoid fever in a population of 5 million for

TABLE XIII

Weighted Mean Coliform Densities of Open Waters Omitting Area 4.

Coliform Density	New Jersey			New York		
	% of Area	Est. Coliform Density	Product	% of Area	Est. Coliform Density	Product
Above 500	4.3	1500	6450			
100-500	32.0	224	7170	8	100	800
50-100	28.0	71	1990	49.4	71	3150
Below 50	35.7	30	1050	42.6	30	1280
Weighted Mean Density			167			56

greater New York, or 0.05 cases per 1000 population, the estimated E. typhosa per million coliforms from Figure 14 would be 6, giving 2400 as an estimated total E. typhosa in the total annual clam production as dug from Raritan Bay. Applying the figure of 1.5 per cent as derived from "diffuse" water epidemics for the percentage of cases of typhoid fever in a general population which develop following the ingestion of a single typhoid bacterium one would arrive at a figure of 36 cases according to the theory of single cell infections. Such a figure is unquestionably considerably out of line with the known epidemiological evidence of present low typhoid morbidity rates and is developed in this manner to emphasize the potential hazards of shellfish production from polluted waters and the factors which probably interpose to prevent shellfish-borne typhoid fever. This figure of 36 cases per annum is a hypothetical figure based upon the assumption that all clams are eaten raw, immediately upon being taken from the bay, by the same distribution of population as consumes polluted water during a water-borne typhoid fever epidemic. Actually, probably not more than half of these shellfish are consumed in a raw state, which brings the potential cases down to 18. Some allowance must also be made for decreases in E. typhosa within the shellfish during the period intervening between digging and marketing which probably averages about seven days. Even assuming a probably high figure of 1/6 of the E. typhosa surviving, the cases would drop to 3. In addition some further allowance should probably be made for the selected population normally consuming shellfish, for most shellfish are consumed by habitual shellfish eaters, usually adults with a probable relatively high level of immunity against typhoid fever.

The assumption of a decrease of 5/6 in the numbers of *E. typhosa* present within a period of one week may seem high. There is little quantitative data available upon the subject. Kinyoun(57) found that typhoid bacteria survived for 18 days in stored shell oysters at both 10° and 0°C. after 24 hours feeding upon water containing 2/3 liter each of 24 hour bouillon cultures of Rawlins and Hopkins strains of *E. typhosa* in 13-16 liters of aquarium water. These were, of course, tremendous infections. The Interstate Sanitation Commission(58, p.123) has summarized investigations upon longevity of typhoid bacteria in oysters, indicating survival periods up to 60 days. The assumed survival of 1/6 of those present after seven days, while extremely low compared to rates of natural purification in polluted waters, may not be far off as it is quite likely that there is a slow average decrease of pathogens in properly stored shellfish.

With these assumed and admittedly rough factors of safety the estimates of possible shellfish borne typhoid from Raritan Bay hard clams, according to the theory of single cell infections, begin to approach known epidemiological evidence, i.e., that there are, at most, few cases of typhoid fever in New York City derived from the ingestion of raw shellfish dug from approved sources of shellfish. It is not possible to go beyond this statement with available data either in stating the

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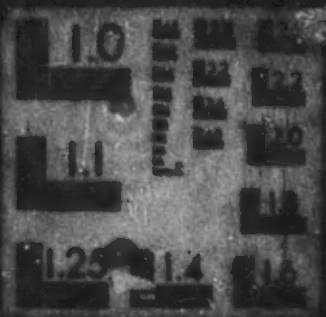
1.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

presence or absence of such hypothetical cases. The evidence does indicate, however, the desirability of reducing total coliforms in market clams from this area. It is also interesting to note that if a heavy or fairly heavy minimum infectious dose is assumed for typhoid fever, there would be little chance of contracting typhoid fever from present open areas of the bay inasmuch as ten million coliforms would be required in a 100 ml. meal of raw, hard clam meats to give an estimated intake of even 60 E. typhosa.

A brief consideration of typhoid fever in Greater New York seems desirable even though it gives no definite answer to the present problem. The 1939 Annual Report of the New York City Health Department(59, p.154) gives the following data on typhoid fever cases for the years 1935-1939, inclusive:

	1935	1936	1937	1938	1939
Total cases reported	349	334	299	312	198
Due to shellfish (all from unapproved sources)	46	12	14	16	7
Contracted out of town	97	74	89	122	40
Mode of infection undetermined	135	121	130	111	94

It will thus be seen that during recent years, in roughly half of 200 total cases of typhoid fever, the source of infection was not determined. In Figure 21 is shown the seasonal

(Insert Figure 21)

distribution in 155 such cases of undetermined source during the years 1939 and 1940, plotted according to dates of onsets within 15 day periods. Most of these infections have onsets in the months of July to November, with a secondary rise during March, April and May. Cases with onsets in December, January and February are low, particularly the latter two months. Any picture of total infections from the ingestion of shellfish taken from approved areas which might be derived from this chart would be dominated largely by oyster consumption which begins in September, the marketing of raw oysters being forbidden during the months of June, July and August within the city of New York.

That cases of typhoid fever due to shellfish from approved sources, if such occur, are quite low, is indicated by the fact that during the years 1939 and 1940, about 12 cases were referred to the Shellfish Division, New York City Health Department for investigation as having consumed raw shellfish from approved sources within the incubation period of 30 days prior to onset. This is somewhat under 10 per cent of the "source unknown" cases or about the percentage of shellfish consumers one would expect to find in the general population. Lumsden, Hasseltine, Leake and Veldee(60) found that the percentage of population consuming raw shellfish within a 30 day period (winter) varied considerably with the economic status of the group considered. During November, 1924, 13 per cent of a control group representative of the general population of Washington, D. C., reported the consumption of raw shellfish. A total of 5.6 per cent of a Chicago, Illinois, group, fair to poor in economic status had eaten shellfish, while 12.7 per cent and 17.1 per cent were similarly reported among those of good and relatively high economic status. In New York, N. Y.

10.18 per cent of a control group reported having eaten raw oysters. Seasonal variations must, however, be taken into account, inasmuch as these surveys were made during the winter.

The completeness of data upon the consumption of shellfish from approved sources within a thirty day incubation period is, of course, open to question in view of the difficulty of remembering such information, but on the whole, the previous statement that such cases, if they occur, are few in number seems warranted.

VI. RECOMMENDATIONS.

In the foregoing discussion there has been attempted the development of a rational approach to the public health problem presented by the taking of clams from a moderately polluted area. While much of the base data is somewhat sketchy, and definite proof of the theory of single cell infections is lacking, there has been presented, nevertheless, sufficient evidence to indicate that occasional cases of typhoid fever can develop from areas which are polluted with sewage to the degree present in Raritan Bay. These studies, therefore, indicate the desirability of decreasing the total of coliform and, therefore, (quite probably) of E. typhosa ingested through the consumption of raw clams from such sources. As to the existence of an imaginary line, on one side of which shellfish are safe for consumption and on the other side of which they are unsafe, it is obvious that there is no such line even though it may be necessary to assume one for the purposes of control. The indications are that any shellfish polluted by coliforms of sewage origin are potentially a source of typhoid fever regardless of the absence of traceable outbreaks of this disease from such sources.

It is believed, therefore, that the most feasible method of reducing the danger of infection from the ingestion of raw hard clams is through the adoption of an arbitrary standard which would reduce to a satisfactory degree the estimated total coliform content of the annual production of

Raritan Bay hard clams. Present standards in use by the New York State Conservation Department for acceptable waters for shellfish production limit to 50 per cent the average ratio of one ml. portions of water which can be positive for coliforms. This approximates a limiting M.P.N. density of 70 per 100 ml. for coliforms. Applying this limit to Raritan Bay waters, about 29 per cent of the present New York open area and 41 per cent of the present New Jersey open area would be excluded (omitting area 4 in New Jersey from consideration as it produces little shellfish). Applying these figures directly to a total clam production of 175,000 bushels per year would give an estimated 122,000* bushels produced from waters of less than 70 coliforms per 100 ml. With an average overlying water coliform content estimated at 50 per 100 ml., then 60 per cent of these shellfish should exceed by 1.3 times the average coliform content of the overlying waters, or an average of 39 coliforms per 100 ml. of whole clam meats and liquors. Applying this on the basis of 9 pounds of clam meats per bushel and 4.5 hundreds of ml. per pound gives 193 million estimated total coliforms in the revised annual production figures compared to 400 million from present production. This is a reduction of about 50 per cent, which seems satisfactory. Therefore, 70 coliforms per 100 ml. on the basis of averaged results from waters overlying the shellfish beds, is

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(*) This estimate is subject to several appreciable sources of error, particularly the distribution of clams throughout the bay.

recommended as the limiting allowable standard for the taking of hard clams to be eaten raw.

It seems desirable at this point to recapitulate briefly and concisely the basis, as presented in this report, for the 70 per 100 ml. limiting standard. It is essentially a compromise between the potential dangers of intestinal infections, as developed by the theoretical considerations presented, and the indicated comparative rarity (possibly complete absence) of actual infections due to shellfish from approved sources under present conditions. The recommendations are based upon meager data and the recommended limiting standard should be more accurately evaluated by extensive studies at the earliest opportunity. The data presented are, however, believed to be the best available at the present time.

As to the application of the recommended limiting standard of 70 coliforms per 100 ml. to Raritan Bay, there are shown in Figure 22 suggested lines which conform to this standard. It will be observed that the lines follow present practice of maintaining closed areas for a given distance off shore and conform, approximately, to the line of 70 coliforms per 100 ml., utilizing the nearest prominent landmark or buoy as a marker. It should be emphasized that the lines shown on Figure 22 are given merely for illustrative purposes as no authority exists for the setting of closed area boundary lines in this report.

(Insert Figure 22)

It will be observed that the suggested closed area off shore is increased to one-half mile for the New York shore while that off the New Jersey shore is left as it is at present. This suggestion conforms to the indicated line of 70 coliforms as shown on Figure 22, which line lies beyond 1/4 mile from the New York shore.

It should be pointed out that no account is taken in these estimates of increased coliform content of the overlying waters during periods of high land water discharge as shown in Figure 5 for a survey made in 1940 by the New York State Conservation Department. It is possible that allowance should be made for this added hazard by applying a factor derived from a study of the annual land water discharged into waters tributary to the bay but the basic data are not available for a study of this hazard at the present time.

It is beyond the scope of this report to discuss general shellfish sanitation but one item should be emphasized, particularly in view of previously recorded findings. This relates to the elimination of casual fecal discharge in waters overlying shellfish beds and the necessity of disinfecting the sewage or sewage effluent from small sources of pollution regardless of the fact that such sources may add relatively small numbers of coliforms to the surrounding waters. It must be remembered that under such conditions the $\frac{\text{pathogen}}{\text{coliform}}$ ratio may become tremendously high and result in serious infection of shellfish in the vicinity.

Future Studies.

As to possible future directions in which studies of standards for hard clams might be carried out, one of the most promising lines would seem to be the determination of different standards for winter and summer, based upon low coliform contents of clam meats and liquor during the hibernation period, below 4°C. For example, some such scheme as limiting the taking of clams to 50 coliforms per 100 ml. water during the months of April to November inclusive with a relaxation of the standard to allow the taking of clams from water containing 100 or less coliforms per 100 ml. during the months of December, January, February and March might be satisfactory. Such an arrangement would be regarded as giving about the same effective reduction of total coliforms as a 70 per 100 ml. standard. This would allow, from Table XIII, shellfish production from 35.7 per cent and 42.6 per cent respectively of New Jersey and New York present open areas during eight months of the year. During the remaining four months production would be allowed from an additional 28 per cent of the New Jersey area and 49.4 per cent of the New York area. The actual production figures under such a scheme are problematical but might not drop appreciably from present levels and if one assumed 100,000 bushels of clams dug during the summer from water averaging 30 coliforms per 100 ml., the total coliform content of the annual production of hard clams from Raritan Bay would be estimated at: 100,000 x 30 x 1.3 x 9 x 4.5 or 158 million, compared to 400 million at present and 193 million from 70 coliforms, or less, per 100 ml. of water. Under such a scheme difficulties of control would have to be considered and might be the determining factor.

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TABLE 1

Individual Analyses of Inlet Waters

Coliforms per 100 ml.

Point	7 A.M.	9 A.M.	11 A.M.	1 P.M.	3 P.M.	5 P.M.
Rockaway Inlet - Apr. 28, 1941						
1	4900	2300	2200	4900	1700	1700
2	3300	2300	1300	490	1300	1700
3	3300	3300	2300	790	240	1300
4	4900	790	1700	2400	2400	1700
5	3100	1700	1700	1700	3300	1100
Rockaway Inlet - May 19, 1941						
1	1700	490	790	1400	330	790
2	920	490	490	2200	790	490
3	7900	230	790	790	2400	230
4	7900	490	330	2200	490	490
5	7000	4900	130	3300	330	330
Rockaway Inlet - June 9, 1941						
1	3300	3300	2300	790	790	330
2	13,000	3300	3300	3100	2200	330
3	7000	2300	3300	790	790	1700
4	3300	2300	2300	790	330	7900
5	3300	1700	2600	1300	17,000	230
Raritan River - May 6, 1941						
6	790	1700	330	330	230	170
7	490	1100	1100	490	330	170
8	1300	1400	490	330	330	240
Raritan River - May 20, 1941						
6	-	490	* 20	220	20	230
7	* 20	210	220	170	130	20
8	130	78	490	20	20	110

(*) Equal to or less than.

TABLE 1 (Continued)

Coliforms per 100 ml.

Point	7 A.M.	9 A.M.	11 A.M.	1 P.M.	3 P.M.	5 P.M.
Raritan River - June 2, 1941						
6	1300	790	790	330	260	130
7	230	490	460	360	330	410
8	330	790	460	230	130	130
Raritan River - June 23, 1941						
6	170	230	130	170	490	330
7	330	700	170	330	230	490
8	170	130	790	68	330	1300
Arthur Kill - May 5, 1941						
9	230	490	1100	790	490	1700
10	310	790	230	330	330	490
11	240	1300	700	490	330	2400
Arthur Kill - May 20, 1941						
9	140	78	230	490	78	78
10	230	330	490	330	78	78
11	230	490	220	330	220	78
Arthur Kill - June 2, 1941						
9	130	230	460	130	68	330
10	130	330	330	130	45	210
11	170	230	170	170	260	110
Arthur Kill - June 23, 1941						
9	45	110	220	490	130	340
10	110	170	490	170	330	130
11	130	330	110	330	490	130

TABLE 1 (Continued)

Coliforms per 100 ml.

Point	7 A.M.	9 A.M.	11 A.M.	1 P.M.	3 P.M.	5 P.M.
Narrows - May 12, 1941						
12	13,000	24,000	3100	1300	7900	17,000
13	11,000	7900	4600	3300	2400	22,000
14	35,000	14,000	1700	3300	4600	35,000
15	7000	7900	4900	3300	3300	3500
16	7900	4600	1700	7900	7900	24,000
17	13,000	4600	2200	3300	24,000	35,000
18	4900	13,000	1300	7900	11,000	24,000
19	4600	7900	11,000	17,000	7900	92,000
Narrows - May 26, 1941						
12	7900	7900	4900	3300	3300	7900
13	3300	22,000	2400	2200	7900	9500
14	2400	13,000	4600	3300	11,000	13,000
15	17,000	4900	13,000	1300	9500	18,000
16	7900	17,000	7900	4900	3300	11,000
17	7900	2400	7000	4900	7900	4900
18	4600	7900	2400	11,000	7900	17,000
19	13,000	17,000	7900	54,000	3300	11,000
Narrows - June 16, 1941						
12	35,000	13,000	4900	1700	1700	700
13	24,000	11,000	13,000	2200	1100	790
14	13,000	13,000	13,000	3100	2400	1100
15	17,000	13,000	7000	4900	11,000	490
16	13,000	13,000	17,000	2400	920	1300
17	7900	11,000	22,000	1700	3300	490
18	13,000	24,000	24,000	3300	790	490
19	7900	22,000	7900	2400	1700	950
Narrows - June 30, 1941						
12	17,000	35,000	4900	11,000	7900	11,000
13	35,000	11,000	3300	7900	3300	1700
14	13,000	17,000	4600	4900	3100	3300
15	13,000	24,000	13,000	7900	3300	2200
16	17,000	22,000	13,000	4900	4900	4900
17	7000	54,000	7900	4900	4900	35,000
18	11,000	35,000	7000	4900	2400	28,000
19	11,000	13,000	13,000	4900	4900	24,000

TABLE 2

Individual Analyses of Bay Water Samples

Coliforms per 100 ml.

Area 1

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
89	79	280	73	79
	33		46	33
	130		23	7.8
91	79	920	13	130
	17	79	170	330
	170		130	240
93	33	350	130	79
	7.8	240	70	79
	220		330	33
95	110	49	33	210
	4.5	7.8	* 2.3	790
	79		23	79
96	33	170	49	79
	6.8	4.5	33	330
	49		49	49
98	49	170	79	79
	6.1	79	33	79
	170		33	11
100	49	240	110	130
	7.8	33	33	79
	330		23	7.8
105	33	23	33	350
	2	2.0	* 2.3	79
	140		33	2.0
109	49	31	49	33
	4.5	22	4.0	49
	33		13	7.8
110	22	33	79	33
	4.5	6.8	* 2.3	11
	49		79	22

(*) Equal to or less than

Table 2 (Continued)

Coliforms per 100 ml.

Area 2

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
33	540 16,000	920 5400 2.0	* 23 4.5	3500 490
35	170 790	1600 330 2.0	790 1300	3500 2400
37		** 2400		
44	79 110	920 330 240	330 1100	240 790
46	110 230	540 790 240	2400 490	950 3500
48	350 9200	920 5400 330	20 22	240 330
68	49 130	1600 330 13	20 49	27 130
70	79 170	540 460 1300	490 350	490 1300
72	46 230	920 230 240	1300 3500	79 700
79	130 330	920 230 79	20 240	49 130
81		540		
83	33 120	540 330 13	130 17	130 330

(*) Equal to or less than.

(**) Equal to or greater than.

Table 2 (Continued)

Coliforms per 100 ml.

Area 3

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
27	110, 33 70, 2.0	46, 6.1 * 2.3	130, 23 2.0	33, 17 79, 13
28		46		
29	23, 33 23, 2.0	170, 9.2 * 2.3	49, 13 2.0	49, 23 13, 49
30	490, 79 330, 7.8	110, 7.8 2.0	7.8, 6.8 13	22, 13 33, 17
31	240, 3500 130, 7.8	110, 23 13	7.8, 7.8 4.0	170, 490 130, 790
62	17, – 11, 7.8	79, 23 * 2.3	23, 7.8 * 2.3	33, 110 33, 6.8
63	22, – 22, 11	33, 17 13,	33, 6.8 2.0	33, 70 23, 7.8
64	23, 11 79	79, 4.5 2.0	4.5 1.8 4.5	33, 23 49, 13
65	7.8 17 13	49 2.0 * 2.3	23 *2.3 2.0	70, 13 4.5 33
66		130		
85	330, 49 7.8	240, 7.8 6.8	13, 4.5 79	23, 13 4.5 49
86	49, 17 49	46, 4.0 6.8	49, 6.8 13	49, 13 240, 49

(*) Equal to or less than

Table 2 (Continued)

Coliforms per 100 ml.

Area 4

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
18	13	49 49 49	220 170 31	170
20	220	170 33 79	330 110 130	130
21	170	330 79 79	240 49 33	240
22	79	170 49 23	330 33 49	330
24	7.8	70 33 33	490 79 33	170
26	79	33 17 7.8	170 17 33	130
55	17	7.8 13 13	170 13 11	23
57	7.8	49 11 26	330 49 23	110
59	23	79 49 33	170 2.0 49	130
60	7.8	79 2.0 4.5	46 7.8 4.5	110

Table 2 (Continued)

Coliforms per 100 ml.

Area 5

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
12	240	1200	3300	330
	33	240	24,000**	130
	46	3500	1100	170
14	* 2.3	790	3300	130
	110	240	130	64
	33	2400	1300	240
	79			
15	240	790	790	1300
	240	240	170	5400
	9200	1700	1100	490
16	490	2200	2200	790
	1300		7.8	5400
	3500	3500	330	5400
17	130	790	1700	490
	2400	110	79	3500
	130	2400	1700	240
	2200			
18	330	3300	3300	790
	170	33	2400	130
	70	3500	2400	790
25	110	9500	3300	790
	1700	1700	5400	5400
	790	1300	24000 **	400
26	330	4900	1300	790
	700	170	79	9200
	79	3500	240	1300
	1500			
27	700	2200	790	240
	330	23	49	2400
	1700	240	33	9200
28	1100	330	1400	1300
	33	13	330	33
	2400	330	22	2400
	49			
29	790	460	790	1300
	1100	790	1300	3500
	1300	79	79	5400
	5400			
30	3300	280	330	2400
	14	790	9200	240
	790	1700	460	5400
	330			
31	700	2800	1300	2400
	790	9200	24000 **	1300
	9200	2400	9200	5400
46	330	4500	7900	3300
	2400	5400	5400	5400
	790	9200	24000 **	790

(*) Equal to or less than.

(**) Equal to or greater than.

Table 2 (Continued)
Coliforms per 100 ml.

Area 6

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
2	130, 33	33, 78 4.5 240	330, 2.0 79	7900, 1300
6	70, 23	33[illegible] 45 [illegible].8 33	49, *2.3 49	460, 790
7	700, 79	110, 110 7.8 33	33, 2.0 49	540, 490
8	3300, 220	220, 20 49, 46	33, 13 49	170, 110
9	3300, 49	330, 170 330, 110	49, 2.0 11	4900, 79
10	790, 490	3300, 130 3500, 790	330, 79 33	2400, 330
11	3300, 330	790, 790 2400, 16000	170, 23 17	3300, 130
12	2400, 33	1100, 490 460, 1700	33, 49 33	1700, 330
13	790, 11	3300, - 33 23	130, 17 4.5	170, 70
14	1300, 11	1300, 330 46, 13	23, 11 7.8	17, 33
53	1100, 17	3300, 230 110, 17	17, 33 2.0	130, 23
54	790, 17	3300, 790 240, 49	33, 22 23	790, 46
55	490, 46	2400, 330 1100, 1100	33, 23 7.8	3300, 110
56	49, 1300	790, 130 130, 49	17, 4.0 2.0	1800, 49
57	1300, 22	700, 230 49, 130	79, 23 49	110, 79
58	790, 4.5	240, 230 130, 33	33, 6.8 33	79, 13
73	79, *2.3	79, *23 4.5 7.8	6.8 4.5 2.0	68, 2.0
74	330, 7.8	240, 20 22, 130	13, 2.0 2.0	400, 23
75	790, 49	70, 110 - 110	23, 23 31	240, 220
76	2100, 79	92, 68 7.8 79	33, 13 17	79, 130

(*) Equal to or less than.

Table 2 (Continued)

Coliforms per 100 ml.

Area 7

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
15	33, 33 2.0	130, 49 13, 2.0	79, 49 17	46, 23 23, 49
16	17, 4.5 4.5	79, 23 23, *2.3	49, 49 2.0	6.8 33 9.3 7.8
17	23 13 13	46, 13 4.5 2.0	110, 49 7.8	23, 6.8 23, 11
18	17, 7.8 *2.3	33, 49, 13, *2.3	79, 79 33	23, 7.8 79, 23
19	11, 2.0 *2.3	33, 23 33, 2.0	79, 140 22	23, 7.8 49, 13
38	4.5 4.5 2.0	49, 330 21, 11	64, 330 330	49, 33 49, 46
39	17, 13 2.0	240, 70 33, *2.3	4.5 1.8 23	130, 7.8 49, 79
40	4.5, 11 4.5	79, 33 7.8 *2.3	33, 33 7.8	33, 7.8 13, 33
41	4.5, 17 *2.3	49, 170 11, 2.3	33, 23 13	46, 17 13, 79
49	*2.3, 4.0 4.0	49, 70 23, *2.3	49, 33 23	17, 7.8 49, 33
50	13, 17 1.8	79, 33 6.8 *2.3	79, 49 7.8	49, 4.5 23, 7.8
51	14, 13 4.5	61, 23 22, *2.3	23, 79 7.8	79, 11 33, 4.5
52	13, 79 2.0	110, 170 4.5 11	79, 33 13	33, 7.8 4.5, 79
59	130, 330 4.5	490, 240 22, 2.0	49, 13 13	170, 13 13, 130
60	31, 4.5 *2.3	330, 330 49, 2.0	49, 33 4.5	79, 13 4.5 330
61	33, *2.3 *2.3	79, 790 70 2.0	23, 17 13	330, 49 14, 46
62	4.5, 7.8 *2.3	79, 790 110, *2.3	23, 79 2.0	110, 23 2.0 7.8
63	13, 2.0 1.8	130, 490 49, 4.5	6.8 23 4.5	23, 2.0 23, 23
64	7.8, 11 2.0	70, 240, 12, *2.3	33, 170 4.5	49, 7.8 13, 23
66	2.0, 4.5 68	33, 490 13, 7.8	33, 49 240	33, 4.5 49, 11

(*) Equal to or less than.

Table 2 (Continued)

Coliforms per 100 ml.

Area 8

Sampling Point	Tide Conditions			
	High	Half Ebb	Low	Half Flood
20	23, 7.8 2.0	79, 13 7.8 13	31, 23 79	79, 79
21	13, 2.0 7.8	490, 23 11, 33	49, 49 49	49, 49
22	13, 7.8 14	240, 7.8 17, 240	49, 40 490	33, 130
23	33, 49 2.0	330, 33 79, 110	79, 130 130	49, 110
24	22, 64 17	330, 110 330, 170	210, 490 110	70, 170
30	7.8, 49 79	240, 49 130, 240	490, 240 460	130, 330
32	49, 110 23	130, 40 33, 490	790, 220 170	79, 23
34	2.0, 9.3 7.8	33, 23 23, 33	49, 79 130	33, 2.0
35	17, 2.0 11	33, 33 79, 33	23, 79 33	33, 7.8
36	220, 13 17	170, 79 13, 79	23, 460 490	330, 13
37	110, 49 23	49, 23 33, 17	17, 49 240	330, 13
42	49, 23 22	17, 33 7.8, 22	49, 33 23,	13, 13
43	17, 11 4.5	23, 49 64, 79	49, 23 23	33, 33
44	2.0 6.8 4.5	68, 33 33, 26	330, 49 240	23, 7.8
45	13. 110 2.0	330, 95 33, 330	460, 330 240	110, 23
46	7.8, 2.0 4.5	79, 23 70, 79	170, 130 70	70, 23
47	23, 6.8 2.0	130, 23 13, 79	110, 130 79	33, 23
48	23, 23 13	49, 13 7.8, 13	33, 17 79	70, 13

TABLE 3

Summary of Hard Clam Samples

Location (Station)	M.P.N.	
	Clams	Water
	Area 1	
93, 95, 96	45	125
89, 91, 98	78	150
93, 95, 96	220	125
107, 109	1300	40
110, 113	330	30
93, 95, 96	330	125
89, 91, 98	560	150
93, 95, 96	790	125
89, 91, 98	790	150
93, 95, 96	840	125
89, 91, 98	310	150
100, 106	170	50
105, 110	130	45
99, 100	330	50
107	110	32
110	*23	30
96	110	78
92	68	180
99, 100	120	70
89	330	112
92	45	200
96	78	78
95	110	118
105	40	59
106	170	40
88	20	60
89	230	112
91	330	231
92	45	200
95, 96	45	100
101	330	60
106	68	40
96	68	78
90	78	170
91	*23	231
96, 101	110	70
106, 107	20	40
101	130	65
111	78	32
92	40	200
97	220	125

(*) Equal to or less than.

Table 3 (Continued)

Location (Station)	M.P.N.	
	Clams	Water
Area 2		
35, 44, 46	230	900
48, 33	230	2500
35, 44, 46	490	900
33, 47, 48	220	2000
68, 70	120	500
81	45	300
68	68	213
84	20	100
70	110	945
72	78	848
Area 3		
30, 31	230	200
27, 29	45	35
30, 31	310	200
27, 29	230	35
30, 31	3500	200
27, 29	1300	35
51	20	50
30, 31	20	200
27	20	40
52	*23	30
27	20	40
52	20	25
Area 5		
28, 29. 30	2300	1500
Area 6		
74, 75	220	150
74, 75	93	150
Near 74	20	125
Near 73	*20	30
72	110	100
72	68	100
73	*20	27

(*) Equal to or less than.

Table 3 (Continued)

Location (Station)	M. P. N.	
	Clams	Water
	Area 7	
Near 61	*20	100
Near 38	*20	100
40, 41, 49, 50	78	30
15, 16, 52	140	40
40, 41, 49, 50	37	27
Near 16	78	30
49, 19	130	30
Near 62	40	85
Near 60	2400	80
Near 49	45	25
Near 61	*20	95
Near 49	*20	25
19, 69	45	50
19, 69	230	50
68	*20	70
69	130	85
38, 41	170	60
68	*20	70
62	78	80
68	170	70
68	45	70
W. of 73	210	50
Near 73	45	30
62	130	80
68	110	75
61	78	95
62, 68	45	75
Near 73	45	30
68, 69	120	80
	Area 8	
Near 48	*20	30
Near 42	110	50
Near 35	45	30
37, 42, 43	110	50
Near 42	*20	25
Near 36	230	100
Near 49	330	25
Near 47	*20	50
Near 42	*20	25
43	*20	30
42	270	25

(*) Equal to or less than.

Table 3 (Continued).

Location (Station)	N.P.N.	
	Clams	Water
Area 8 (Continued)		
21	*20	61
45	20	160
37	78	91
42, 43	61	30
47	40	50
36, 37	*20	100
48	20	31
43	45	32
47	*20	51
48	20	31
42	*20	25
20	20	41
21, 47	*20	55

(*) Equal to or less than.